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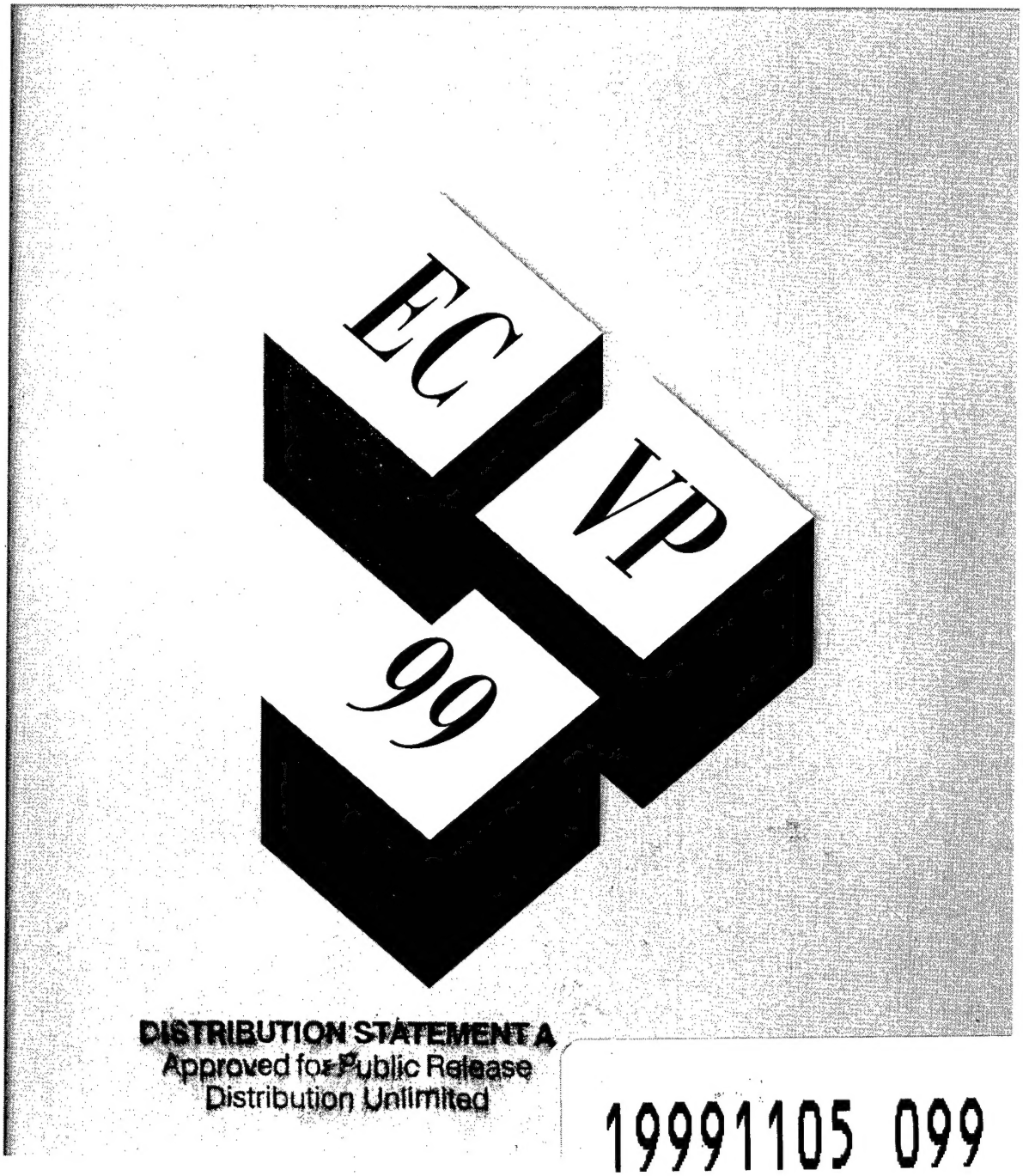

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Abstracts

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FOR ECVP99 ON WWW SEE INSIDE BACK COVER

ECVP

The European Conference on Visual Percepton is an annual event. Previous conferences took place in:

1978 Marburg (D)	1979 Nordwijkerhout (NL)	1980 Brighton (GB)
1981 Gouvieux (F)	1982 Leuven (B)	1983 Lucca (I)
1984 Cambridge (GB)	1985 Peñiscola (E)	1986 Bad Nauheim (D)
1987 Varna (BUL)	1989 Zichron Yaakov (ISR)	1988 Bristol (GB)
1990 Paris (F)	1991 Vilnius (LIT)	1992 Pisa (I)
1993 Edinburgh (GB)	1994 Eindhoven (NL)	1995 Tübingen (D)
1996 Strasbourg (F)	1997 Helsinki (FIN)	1998 Oxford (GB)

Next year's conference is planned to take place in Groningen (The Netherlands).

ECVP '99 Abstract

SUNDAY

THE SEVENTH KANIZSA AND PERCEPTION LECTURE

◆ **The phenomenal science and art of perception**

R L Gregory (Department of Experimental Psychology, University of Bristol, 8 Woodland Road, Bristol BS8 1TN, UK; fax: +44 117 928 8461; e-mail: Richard.Gregory@bris.ac.uk)

Perception gives our most immediate knowledge of the world of objects. Yet as science advances, our perceptions depart ever further from conceptions of physical realities. This makes 'illusion' hard to define. For if illusions are departures from physics (fortunately revealing processes of perception through the differences), how can we avoid saying that all perceptions are illusory, when physics gives such different accounts of objects? It is important, though difficult, to define 'illusion'. It is also important to classify phenomena of perception, as classifications can help to interpret experiments and they point to gaps in understanding. This is evident in the power of the Periodic Table of the Elements to make sense of chemistry, and classifications of species to reveal biological relationships and origins. Classification of phenomena of perception should be theoretically suggestive and practically useful, and it might even help to bridge the science of perception with the practice and appreciation of art. We see perception as brain-based, which raises ancient and modern questions of brain function. Some problems of interpreting functional brain imaging are considered.

MONDAY

SYMPOSIUM

OPTIC FLOW AND HEADING

◆ **Optic flow and proprioceptive information for control of heading**

M S Banks (Vision Science Program and Department of Psychology, University of California at Berkeley, Berkeley, CA 94720-2020, USA; fax: +1 510 642 7679; e-mail: marty@john.berkeley.edu)

In order to guide motor activity, the visual system must determine the layout of the scene, the direction of self-motion, and the direction of other moving objects with respect to the body. Its ability to do so is remarkable given that images move on the retina, the eyes move in the head, the head moves on the body, and objects can move within the scene. In this symposium on self-motion perception, we present perceptuomotor, psychophysical, physiological, and theoretical work on the problem of estimating self-motion with respect to the environment. I present an overview of issues to be addressed and discuss some recent psychophysical work from my lab. There has been a great deal of experimental and theoretical work examining the means by which the visual system estimates self-motion paths during a change in gaze direction. Gaze changes alter the flow field at the retina so the system must take the alteration into account in order estimate self-motion paths veridically. I discuss the use of high-level visual cues and eye-muscle, neck-muscle, semicircular-canal, and otolith signals in self-motion estimation.

◆ **Control of walking from optic flow**

W Warren, B A Kay (Cognitive and Linguistic Sciences, Brown University, Box 1978, Providence, RI 02912, USA; fax: +1 401 863 2255; e-mail: Bill_Warren@brown.edu)

Humans can accurately judge their direction of self-motion (heading) from optic flow, but do they use it to control locomotion? Gibson proposed that steering could be controlled by keeping the focus of expansion (FOE) near one's goal—the FOE strategy. But there are positional strategies that do not rely on optic flow at all. In the thrust strategy, effector force is applied in a direction opposite the egocentric direction of the goal; in the centring strategy, one moves so as to centre the goal at the body's midline. Subjects were asked to walk through a narrow doorway in a virtual environment. Optic flow and positional strategies were dissociated by offsetting the FOE by 5 deg from the actual direction of walking, so that if participants used the FOE strategy they would show a heading error. Time series of heading error suggest that participants initially use a positional strategy, but after about 1 s switch to an optic flow strategy. Both positional and optic-flow strategies thus appear to be available. The visual conditions under which they are each exhibited are being investigated.

◆ **When do we use optic flow and when do we use perceived direction to control locomotion?**
B J Rogers, R S Allison (Department of Experimental Psychology, University of Oxford, South Parks Road, Oxford OX1 3UD, UK; fax: +44 1865 310 447; e-mail: bjr@psy.ox.ac.uk)

Optic-flow-field analyses have revealed that there are several sources of information to indicate the point of impact in a visual scene for a moving observer. Visual information alone, however, cannot indicate the heading direction, since heading is defined with respect to the observer. The importance of the distinction between the point of impact and the heading direction was brought out by Rushton et al [1998 *Investigative Ophthalmology & Visual Science* **39**(4) S191] who showed that walking paths are determined primarily by the perceived direction of the target point. In contrast, many studies have shown that the point of impact can be detected with considerable precision by using a variety of different flow-field characteristics, so why doesn't optic flow play a more important role in controlling locomotion? Our results suggest that several factors are important. Locomotor paths are straighter when (i) there is local motion parallax between the intended target and objects at different distances; (ii) there is ground-plane texture and/or path markings; (iii) attention is directed towards the optic-flow cues. In addition, the extent to which we use flow-field information depends on the type of locomotion and the way in which heading direction is controlled by the observer.

◆ **Perception of 2-D simulated self-motion from optic flow**
R J V Bertin, I Israël, M Lappe¶ (LPPA-CNRS, Collège de France, 11 place Marcelin Berthelot, F 75005 Paris, France; ¶ Allgemeine Zoologie, Ruhruniversität, D 44780 Bochum, Germany; fax: +33 1 44 27 13 82; e-mail: rbertin@ccr.jussieu.fr)

A veridical percept of self-motion is normally derived from a combination of visual, vestibular, and proprioceptive signals. A previous study showed that blindfolded subjects can accurately perceive passive movements unless they are turned (whole-body, head-fixed) relative to the trajectory. We tested whether vision allows for better path perception, by correcting or complementing vestibular perception. Subjects were seated, head-free but not moving. They wore an HMD showing optic-flow stimuli simulating 2-D trajectories over a horizontal ground plane. The trajectories were linear and semicircular displacements with the observer's yaw fixed or changing relative to path or space. The stimuli had triangular or constant velocity profiles, and could contain a landmark. After presentation, subjects reproduced the perceived movement with a model vehicle, checking and correcting their reproduction for correspondence with the perceived movement. Position and orientation of the model vehicle were recorded. Visual perception was very similar to vestibular perception. Subjects tended to perceive orientation fixed relative to trajectory or (unlike in the vestibular study) to space, causing trajectory misperception when this percept was incorrect. Velocity profile had no significant influence. The effect of landmark presence is discussed.

◆ **The same perception of self-motion from different combinations of visual and non-visual cues**
M Jenkin, L Harris, F Redlick, D Zikovitz (Department of Computer Science, York University, 4700 Keele Street, Toronto, Ontario M3J 1P3, Canada; fax: +1 416 736 5872; e-mail: jenkin@cs.yorku.ca; WWW: http://www.cs.yorku.ca/~jenkin)

When moving within an environment, vection and vestibular and other cues are integrated to provide a single measure of the distance of self-motion. We have previously reported that for passive, constant-acceleration motion, perception is dominated by the vestibular cue. Here we extend these findings by varying the relative magnitudes of the two cues and by varying the motion profile from constant acceleration to constant velocity. Subjects were placed in an immersive visual environment. The visual display was a simulation of motion along a hallway. A six-degree-of-freedom head tracker permitted the visual display to take into account the subject's head position and simulate the appropriate view. Physical motion cues were provided by moving subjects. Subjects were shown a combination of visual and non-visual cues and pressed a button to indicate when they perceived they had travelled through a previously presented distance. The effectiveness with which subjects could perform this task depended on the magnitude of the motion and the relative magnitude of the visual and non-visual cues. For constant-acceleration profiles, we present a linear model which accurately predicts the perceived distance and demonstrates that there exists a family of visual–vestibular stimulus combinations which give rise to the same perception of linear self-motion.

◆ **Influence of pursuit speed on the representation of heading in macaque MSTd**
K V Shenoy, J A Crowell, R A Andersen (Division of Biology, California Institute of Technology, Pasadena, CA 91125, USA; fax: +1 626 795 2397; e-mail: kvshenoy@vis.caltech.edu)

Forward movement creates an expanding retinal image and the focus of expansion indicates the direction of self motion when eyes are still. Gaze rotations, however, displace the focus of expansion on the retinae by an amount proportional to rotation rate, which would cause heading errors if uncompensated. We recently reported that MSTd neurons use pursuit and VOR-cancellation signals to partly compensate such displacements. Does this compensation change in proportion to pursuit speed? For each neuron ($n = 40$) we created focus-tuning curves by displaying 11 optic-flow patterns with various focus positions ($\pm 30°$ along an axis parallel to the cell's preferred direction of pursuit) while monkeys fixated or pursued targets moving at 2.6, 5.1, and 9.2 deg s^{-1} in the preferred direction. Compensatory tuning-curve shifts increased with pursuit speed (on average 51% of perfect proportional compensation, $p < 0.001$). Identical retinal stimuli, created by fixing gaze and counter-rotating the image, also elicited compensation (30%, $p < 0.001$). These results indicate that as pursuit speed increases, extraretinal and retinal signals drive proportionally increased levels of compensation, as needed for accurate perception.

◆ **Gaze-centred first-order analysis of optic flow based on spatiotemporal filtering of cortical flow fields: a novel view of MST functional properties**
S P Sabatini, F Solari, R Carmeli, P Cavalleri, G M Bisio (Department of Biophysical and Electronic Engineering, University of Genoa, via Opera Pia 11a, I 16145 Genova, Italy; fax: +39 010 353 2777; e-mail: silvio@dibe.unige.it)

Medial superior temporal (MST) cells are probably optimally suited to the analysis of visual motion in terms of first-order elementary flow components (EFCs). To investigate the neurophysiological basis of this perceptual property, we propose a functional model of the visual pathway from the middle temporal (MT) area to MST. At MT level, a wave-like spatiotemporal activation function (cortical flow) is introduced as a physicalist representation of the optic flow that preserves its qualitative properties. At MST level spatiotemporal filtering operations on this activation function approximate a template matching between the optic-flow stimulus and the cell preferences to EFCs. We adopt a gaze-centred representation, in which the optic flow is analysed in terms of how it is related to the fixation point. Each MST model cell is selective to an EFC referred to the fixation point and is characterised by a specific tuning to the mean speed of motion in the optic-flow stimuli. For each MST unit the best stimulus is centred on the fovea, though different stimulus configurations can trigger a cell response, provided that the subpattern of the optic flow locally matches the cell's preference for motion component and speed. Observed physiological properties relating MST cell response to the placement of optic-flow stimuli in the visual field are discussed from this new (gaze-centred) perspective.

◆ **Functional magnetic resonance response to flow-field motion**
M C Morrone, M Tosetti¶, D Montanaro§, D C Burr, A Fiorentini, G Cioni¶ (Istituto di Neurofisiologia, CNR, via S Zeno 51, I 56127 Pisa, Italy; ¶ Istituto Scientifico Stella Maris, Calambrone, I 56100 Pisa, Italy; § U.O. Neuroradiologia, Ospedale S Chiara, I 56100 Pisa, Italy; fax:+39 050 559 725; e-mail: concetta@neuro.in.pi.cnr.it)

We have measured the BOLD fMRI response in humans to stimulation by flow-field motion. The motion was generated on a large dynamic dot display (30 deg × 30 deg, 100 dots, lifetime 300 ms). In the active condition all dots moved coherently to define circular, radial, or translational motion. In the control condition they were either stationary (for their 300 ms lifetime), or each dot moved along a randomly oriented trajectory. When coherent motion of any type was tested against the stationary control, there was a strong BOLD response in MT complex, but none elsewhere, suggesting that the controls were well matched in their spatial and temporal properties. When continuous coherent motion was tested against dynamic noise, there was no measurable response for any type of motion, in any brain area. However, when the coherent motion was caused to reverse direction every 2 s (expansion–contraction, left–right, etc), the response of MT complex (against random dynamic noise that alternated direction every 2 s) was very strong and specific. The results show that when erroneous responses are minimised by use of carefully matched controls, MT complex shows a response selectivity to change of flow-field motion, rather than to a continuous presentation.

◆ **Adaptation to expansion and perceived time to collision: psychophysical and driving-simulator observations**

R Gray, D M Regan¶ (Cambridge Basic Research, Nissan Research and Development, 4 Cambridge Center, Cambridge, MA 02142, USA; ¶ Department of Psychology, York University, 4700 Keele Street, North York, Ontario M3J 1P3, Canada; fax: +1 617 374 9697; e-mail: rgray@pathfinder.cbr.com)

In some situations it is necessary to estimate the time to collision (TTC) of an approaching object after prolonged exposure to retinal image expansion (eg in highway driving). We examined the effects of adaptation to expansion (ATE) on laboratory estimates of TTC and estimates of TTC in a simulated driving task. We used a staircase tracking method to measure estimates of TTC with a simulated approaching sphere based on monocular or binocular TTC information. Estimates made after ATE were compared with estimates made after adaptation to a constant-sized target. We examined overtaking manœuvres in a driving simulator. Manœuvres made after simulated driving on a straight empty road (adapt) were compared with manœuvres made after adaptation to a static scene (baseline1) and after curve driving (baseline2). After ATE estimates of TTC were lengthened by 22% when based on monocular and 12% when based on binocular information. In the adapt condition, drivers initiated overtaking substantially later (220 – 510 ms) than comparable manœuvres made in either of the baseline conditions. This effect could not be explained by changes in driving speed. ATE dramatically altered perceived TTC. In practical driving situations this effect may increase the risk of rear-end collisions.

◆ **Time-to-collision and surface layout**

M G Harris (Department of Psychology, Birmingham University, Edgbaston, Birmingham B15 2TT, UK; fax: +44 121 414 4913; e-mail: harris@bham.ac.uk)

Movement of a surface towards an observer produces a smoothly expanding pattern of retinal flow. Observers can use at least some of the information provided by this flow because expanding 2-D random-dot kinematograms produce a compelling impression of 3-D stimulus approach and allow accurate estimates of time-to-collision (TTC). However, since TTC can be estimated on a point-by-point basis, expanding flow can also, in principle, provide information about surface layout. Here it is demonstrated that human observers are surprisingly poor at making use of this additional, more subtle, information. Random-dot kinematograms depicting movement relative to a slanted plane were used. The surface moved either directly towards the observer (approach condition) or at right angles to this trajectory (parallel condition). Even when the rate of flow was matched, observers were much worse at detecting slant and much more variable in their estimates of slant in the approach condition than in the parallel condition. This is particularly surprising because parallel movement in the same direction as the surface tilt produces a smooth 1-D expansion in the flow.

◆ **Cardinal directions for optic flow**

D C Burr, J Ross¶, D Badcock¶ (Department of Psychology, University of Florence, via S Nicolo 93, I 50125 Florence, Italy; ¶ Department of Psychology, University of Western Australia, Nedlands, WA 6009, Australia; fax: +39 050 559 725; e-mail: dave@in.pi.cnr.it)

Both electrophysiological and psychophysical studies point to the existence of detectors specialised for the analysis of optic flow. However, it is unclear whether these detectors are tuned to specific cardinal directions (such as radial and circular motion), or whether they respond equally to all directions of optic-flow motion, including intermediate spiral motions. We have measured signal-to-noise sensitivity for both detection and direction discrimination for circular, radial, and spiral motion, in the presence of masking stimuli of variable trajectories of optic flow. The masks were not superimposed on the target stimuli, but displayed in adjacent sectors, so as to stimulate complex-motion integratory mechanisms, rather than local-motion mechanisms. For targets with circular or radial trajectories, the masks had maximum effect when they had the same trajectory as the target. However, for targets in spiral motion, the most effective masks were not those similar to the target, but those with radial or circular trajectories. This result implies that radial and circular motion form cardinal directions in optic flow space. This conclusion was reinforced by summation studies, with similar stimuli.

ORAL PRESENTATIONS

LEARNING, MEMORY, AND DEVELOPMENT

◆ **Texture cues to depth can be learned from stereoscopic depth**

J Hillis, F Domini, M S Banks (Vision Science Program and Department of Psychology, University of California at Berkeley, Berkeley, CA 94720-2020, USA; fax: +1 510 642 7679; e-mail: jamie@john.berkeley.edu)

To recover 3-D shape from texture gradients, the visual system must make assumptions about the regularity of the surface texture. Recovering shape from binocular disparity gradients, on the other hand, can be done without assumptions about surface properties. We examined whether the visual system uses stereoscopic information to learn reliable texture cues to depth.

In experiment 1 three distinct types of random textures were probabilistically matched with stereoscopic patterns of side-by-side Gaussian blobs (one coming towards the observer and one going away). Thresholds for detecting depth were measured during repeated learning sessions, where matching between particular stereoscopic depth and textures was invariable and a test session, where the matching between disparity fields and textures was variable. In experiment 2 three distinct types of disparity fields were generated and used in combination with texture patterns that specified right or left side closer. The learning and test sessions were completed as in experiment 1.

Preliminary results indicate that observers learn texture cues to depth from consistent pairing with stereoscopic depth patterns. Whether disparity cues to depth can be learned from pairing with regular texture gradients (experiment 2) is yet to be determined.

◆ **Motion perception and perceptual learning studied by magnetic stimulation**

L Stewart, L Battelli¶, V Walsh§, A C Cowey§ (Department of Psychology, Institute of Cognitive Neuroscience, Queen Square, London WC1 3AR, UK; ¶ Department of Psychology, University of Trieste, via dell'Università 7, I 34123 Trieste, Italy; § Department of Experimental Psychology, University of Oxford, South Parks Road, Oxford OX1 3UD, UK; fax: +44 171 813 2835; e-mail: l.stewart@ucl.ac.uk)

Transcranial magnetic stimulation (TMS) was used to study the perception of visual motion and the learning of a visual-motion task. Moving phosphenes were evoked when stimulation was applied over the likely location of visual area V5, a site over which TMS was then applied during the perception of a movement or colour aftereffect. The duration of the movement but not the colour aftereffect was markedly reduced. A recent study of the effects of TMS on a visuomotor learning task found that stimulation at 1 Hz or 10 Hz, respectively, slowed or accelerated the rate of learning. Extending this paradigm to learning of a purely visual nature, we applied TMS to two groups of subjects during the learning of a visual-motion task. The two groups received either 3 Hz or 10 Hz stimulation. The group receiving stimulation at 3 Hz learned significantly less than the control and the 10 Hz group, which did not differ. Sham TMS had no effect. We suggest that phosphenes induced by TMS can be used as the 'hotspots' of the visual system and that the effects of different temporal rates of stimulation may be generalised across different sensory/motor systems.

◆ **A study on visuospatial working memory**

W X Schneider, M-B Wesenick, H Deubel, C Bundesen¶ (Department of Psychology, Ludwig-Maximilians-Universität München, Leopoldstrasse 13, D 80802 München, Germany; ¶ Psychological Laboratory, Copenhagen University, Njalsgade 90, DK 2300 Copenhagen S, Denmark; fax: +49 89 2180 5211; e-mail: wxs@psy.uni-muenchen.de)

We present a series of experiments on encoding, retention, and retrieval of multidimensional objects in the visuospatial working memory. Subjects were asked to indicate whether a test item was present in a previously shown sample array. The sample array consisted of a varying number (1 – 6) of rectangles that differed in colour, length, and orientation. In various tasks we analysed accuracy of report and reaction time as a function of complexity of the objects, number of feature dimensions, exposure duration, and retention time. The results show that with increasing set size accuracy of report decreases and reaction time increases. Encoding time increases with set size. Furthermore, performance depends on task-specific properties and on the relevant feature dimension. Our data can be modelled by the computational theory of visual attention (Bundesen, 1998 *Philosophical Transactions of the Royal Society of London B* **353** 1271 – 1281). The data reveal a limited processing capacity for encoding and a storage capacity of about three objects. Moreover, our data suggest that the basic unit of the visuospatial working memory refers to integrated objects rather than single features.

◆ **Solid vs line-end inducers in the recognition and transfer of learning for subjective contours**
M Bross (Department of Psychology, Concordia University, 7141 Sherbrooke Street West, Montréal, Québec H4B 1R4, Canada; fax: +1 514 848 4545;
e-mail: mbross@vax2.concordia.ca)
Two experiments were performed to examine some predictions derived from Grossberg (1987 *Perception & Psychophysics* **38** 428–456) that solid (pacman) type of inducers produce faster processing, but slower transfer of learning, than line-end inducers in the recognition of subjective contours (SC). In the first study, subject's reaction times and magnitude estimates of familiar vs unfamiliar geometric shapes for the two types of inducers were measured. The results showed a significant advantage for pacman induced SC, for both measures and both types of shape. In the second study, observers inexperienced with SCs viewed either line-end SC first and solid induced SC second, or vice versa. Results for reaction time and goodness-of-figure direct magnitude estimation replicated the differences obtained in the first experiment, and also yielded a significant interaction indicating that observers who view line-end-induced SC first exhibit greater transfer of learning. Overall, these findings, that certain types of inducers are more difficult to identify and lead to differential transfer of learning, are discussed in terms of how the perception, and learning of SC induced by solid vs line-end inducers can be modeled by drawing on the properties and respective contribution of the feature contour, boundary contour, and object recognition systems as proposed in Grossberg's model.

◆ **Processing of shapes, colours, and letters in short-term visual memory**
J Ninio, E Mizraji (Laboratoire de Physique Statistique, École Normale Supérieure, 24 rue Lhomond, F 75231 Paris cedex 05, France; fax: +33 1 44 32 33 18;
e-mail: ninio@physique.ens.fr)
The time to determine whether two images presented side by side are identical or not provides clues on short-term visual memory (STVM). For arrays of random black or white elements, about 12 elements are held in memory during eye movement from one image to the other, and the comparison time is about 60 ms/element (Brunel and Ninio, 1996 *Cognitive Brain Research* **5** 273–282). Here, 18 subjects compared arrays of black or white quadrangles (1 bit/element); arrays of blue, green, yellow, or red quadrangles (2 bits/element); or arrays of letters belonging to a 16-letters alphabet (4 bits/letter). The subjects differed in their relative performances on letters versus colours or colours versus shapes. However, the subjects-averaged times to decide that two images are different were remarkably consistent, once they were expressed per bit, and not per element (60, 65, and 55 ms/bit for shapes, colours, and letters, respectively). STVM capacity was deduced from the point at which 'same' responses became substantially slower than 'different' responses: around 12 bits for shapes or colours, but 20 bits for letters. Thus, letter processing is not exceedingly rapid, but once encoded, letters are rather well retained.

◆ **A theory of context in perceptual categorisation**
M Jüttner, I Rentschler (Institut für Medizinische Psychologie, Universität München, Goethestrasse 31, D 80336 München, Germany; fax: +49 89 5996 615;
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Categorisation is a major route for organisms to make sense of sensory experience and as such it is highly adaptive to context. However, despite its importance, context is still a vague concept in vision research. Here we propose and test a new theory of context in visual categorisation. It is based on the so-called evidence-based systems (EBS) approach to classification. Originally developed in the area of machine intelligence EBS has been extended to the analysis of human perceptual learning and generalisation (Jüttner et al, 1997 *Journal of Mathematical Psychology* **41** 244–259). It allows the reconstruction of the combination of non-relational and relational features that provide solutions of a given classification problem. Normalised by the total number of feature combinations, this number may be used as a measure of context with respect to the categorisation task. To test the theory, we measured how human observers learn to classify unfamiliar grey-level images, and how they generalise their knowledge to contrast-inverted image versions. Across a wide range of categorisation contexts, EBS simulations were closely correlated with human performance concerning learning duration and generalisation. Our results suggest that visual representations for object recognition evolve so that they become highly adaptive to task and stimulus structure.

◆ **Vision, and the vividness, and latency, of visual images**
A J Reeves, A D'Angiulli (Department of Psychology, Northeastern University, 360 Huntington Avenue, Boston, MA 02115, USA; fax: +1 617 373 8714; e-mail: Reeves@neu.edu)
Visual mental images of simple shapes may reduce detectability (by $< 0.8d'$ units) of visual targets flashed on a display, owing to a loss of sensitivity at a proximal site in the visual pathway (rather than to imagery simply harming accommodation or fixation, or distracting attention; Craver-Lemley and Reeves, 1992 *Psychological Review* **99** 633–649). Does this proximal interference arise because percepts and images share a common substrate? They do, in Kosslyn's mental canvas theory, in which image generation requires that images be retrieved, and then—in a time-intensive process—translated and scaled in a visual buffer to fit the perceived display. However, in Paivio's 'imagens' theory, generation requires retrieval of an appropriately sized image without scaling; following David Hume, we assume that generation time also depends on activation or vividness. We report that RTs to generate more vivid images are much shorter than RTs to less vivid ones, but that neither natural image size, nor display size, nor even lexical access time, much affect mean RTs (though variances do change). These results support the revised version of imagens, and revisit our 1992 conclusion that visual images and percepts do not necessarily share common properties.

◆ **Motion sensitivity in infant and amblyopic macaque monkeys**
L Kiorpes, C Tang, J A Movshon¶ (Center for Neural Science, New York University, 4 Washington Place, New York, NY 10012, USA; ¶ Howard Hughes Medical Institute and Center for Neural Science, New York University, 4 Washington Place, New York, NY 10012, USA; fax: +1 212 995 4183; e-mail: lynne@cns.nyu.edu)
We studied motion sensitivity in normal infant monkeys, and in monkeys with experimentally-induced amblyopia (anisometropic or strabismic). Fifteen *Macaca nemestrina* monkeys ranging in age from 2 weeks to 3 years participated. We used a motion discrimination task; the animals indicated the direction of motion in dynamic random-dot kinematograms. We varied the proportion of dots that carried a coherent motion signal over a range of spatial and temporal displacements. Motion sensitivity develops over a similar time course to contrast sensitivity in infant monkeys. Optimal dot speed shifts from about 40 deg s^{-1} at the youngest ages to adult levels of about 10 deg s^{-1} by 9 months of age. Slow speeds show greater change with age than fast speeds. Overall sensitivity to motion continues to improve up to at least one year of age. Optimal dot displacement at each age was correlated with development of spatial resolution. Amblyopic eyes showed similar performance to young normal monkeys; optimal sensitivity was low and optimal dot displacement reflected the relatively poor spatial resolution. We conclude that the normal development of motion sensitivity and the motion sensitivity of amblyopes, as measured by this direction discrimination task, are related to the development of spatial vision.

◆ **Perceptual learning of visual stability in a virtual environment with conflicting head and retinal motion information**
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We tested whether perceptual learning occurs in a virtual-reality visual environment in which the correspondence between active head-motion and retinal-motion information is modulated. The subject observed a display while moving his head from side to side by following a sound 'moving' along an arc in a horizontal plane. We defined 'gain' as the ratio of 'the angular velocity in the virtual environment' to 'the angular velocity in the real environment' during active head movement. In the first experiment, the subject adapted to a virtual environment (gain = 0.5, 1.0, 1.5) for 3 min as a learning phase. In the test phase, the subject adjusted the gain so as to perceive a 'stable environment' in the test phase. The results showed that adjusted gains in the test phase shifted to the gains in the learning phase. In the second experiment we found that the motor system did not change in the learning phase. These data suggest that perceptual learning of visual stability occurs in the virtual environment in a short period of time, and is a visual type of learning involving the visual motion mechanism.

◆ **Navigation in environments with four spatial dimensions**
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What representations of visual space do we use to navigate in complex environments? Can these representations be used to help navigate in environments with four or more spatial dimensions?

To investigate these questions, we created a 4-D graphic engine to render environments with four spatial dimensions interactively. Using this software, observers moved around a 4-D environment with 18 texture-mapped rooms, linked by corridors and by elevators. Using a freelook interface similar to that found in a first-person action game, observers roamed about the environment searching for a target, a yellow box. The yellow box was placed in a room that varied randomly from trial to trial. Upon finding the yellow box, observers were instructed to go as rapidly as possible back to their starting room, in which was located a red box. If observers can learn the spatial layout of the 4-D environment, then the time taken to return to the starting location should decrease as a function of trial. Indeed, we found that times to return decreased with increasing practice to an asymptotic level close to that associated with ideal performance. Control experiments rule out the possibility that improvement is due to learning the interface. We believe that the spatial knowledge of 4-D environments gained by observers in this task consists primarily of local, route-based information, not global 4-D spatial representations; we are conducting further experiments to clarify these issues.
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IMAGING, PHYSIOLOGICAL, AND CLINICAL STUDIES I

◆ **The role of visual feedback in the performance of a fine motor task versus a ballistic movement task for Alzheimer's disease patients**
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Normal adults depend on visual–spatial feedback for accurate performance at early stages of learning a new motor task but gradually switch to reliance on kinesthetic feedback. We examined whether Alzheimer's disease patients (ADPs) make the switch in a fine motor task and a ballistic movement task. In experiment 1, the rotary pursuit task was administered to 20 ADPs and 20 normals. After determining baseline rotation speed, both groups received two days of training. Afterwards, 30% reduction in visual input was administered. Both ADPs and normals showed significant learning in training. Only the normals were able to compensate for the visual input reduction. ADPs relied more on visual than kinesthetic feedback. In experiment 2, 10 ADPs and 10 normals had their right shoulder abducted to 90° and performed quick spatial aiming ballistic movements at varying distances. Subjects were trained with visual feedback. After training, they were given posttests at the varying distances without visual feedback. After an initial performance drop, both groups improved; no significant differences between the groups were found. Results indicate that, while ADPs cannot compensate for lack of visual feedback when performing a fine motor skill requiring a motor schema, with a ballistic task one less likely to involve complex motor schema, ADPs can compensate for lack of visual feedback.
[Supported by NIH Grant 1Ro1AG13967.]

◆ **Figure–ground segregation: fMRI and EEG correlates**
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Functional magnetic resonance imaging (fMRI) indirectly visualises increased brain activity by means of increased blood flow. Multichannel recording of electrical brain activity provides a more direct means to visualise the same activity with higher temporal but lower spatial resolution. We used both methods to localise brain activation during figure–ground segmentation. The stimuli consisted of a luminance-, colour-, or motion-defined checkerboard. It alternated with a uniform condition corresponding to one of the two check types, eg an all-red field. The fMRI demonstrated a segmentation-specific activation of V1, V2, and V3 on the inflated cortical surface for all subjects and all stimuli. Activation was similar for all stimuli. The EEG recordings yielded activations, especially over the occipital cortex, with a time structure differing among stimuli. In summary, we found cortical activation that was not due to the individual stimulus elements but to the fact that they differed along the borders of the checks. While the mechanisms underlying figure–ground segregation seem to activate similar cortical areas, irrespective of the features defining the figure, the temporal course of the activation may differ between the defining features. Figure–ground segmentation based on luminance, colour, or motion obviously takes place as early as the primary visual cortex.

◆ **Object-selective cortical responses during slit viewing**
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Observers fixating on a narrow slit can perceive an object moving behind the slit even though only small segments of contour are visible at any time (Parks, 1965 *American Journal of Psychology* **78** 145–147). This requires contour integration across both space and time. We attempted to localise the neural substrates of the contour integration process. Neural activity in the occipital lobe was measured with fMRI while observers viewed line drawings of common objects that were (i) fully visible, (ii) slit-viewed, and (iii) slit-viewed but distorted by vertically shifting successive pixels in the slit by differing amounts. This distortion generally maintained the local motion signals from all pixels, but disrupted perceptual integration. Ventral and lateral portions of the anterior occipital lobe showed greatest activity for fully visible objects, followed by slit-viewed objects, with the least activity for distorted slit-viewed objects. Regions showing increased activation for slit-view relative to the distorted slit-view objects were anterior to retinotopically mapped areas, and also showed increased activity for visual object perception compared with texture perception. The neural computations underlying contour integration must be at least partially completed by these stages in the ventral visual pathways.

◆ **Priming and 'noise' in switching between visual search tasks: a TMS study**
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Transcranial magnetic stimulation (TMS) over area V5/MT impairs the ability to perform movement-related complex visual search tasks but can enhance the ability to perform colour/form related search. To investigate the mechanisms of these effects we compared the changes in search performance on the two types of search caused when TMS was applied during blocks of the same trial type or when the trial types were interleaved. TMS over V5 had an enhancing effect on colour/form searches when the trial types were blocked but not when they were interleaved. The effect was limited to interleaving of stimulus types: for example there was no relationship between TMS and changes in responses (target present/target absent) or any response/stimulus interaction. We interpret these findings as evidence that the enhancement of colour/form processing following TMS over V5 is due to a combination of priming and the 'noise' added to the motion system. Our interpretation suggests that competition for attention to visual attributes, which has been studied at the level of individual receptive fields, should be extended to studies of competition between visual areas that process different attributes of the visual scene.

◆ **Physiological basis of backward masking in scene recognition**
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We examined the physiological basis of backward masking by recording evoked magnetic fields with a whole-head MEG-system during a recognition task. On each trial, a digitised image of a natural scene was displayed, immediately followed by a noise mask. Subsequently, the target and a distractor were shown, and subjects had to indicate the target. At 92 ms and 37 ms of presentation time, recognition performance was 97% and 67% correct, respectively. The MEG data revealed that, in the first 80–120 ms, activity was concentrated over the occipital cortex. At the 92 ms target duration, the mask had no effect on the initial activity caused by the target. However, at 37 ms of target duration, processing of the mask briefly interfered with the target. A significant difference in MEG activation in correct and false trials occurred at about 160 ms after target onset. The results indicate that, during the first 40 ms of processing of a natural scene, new information arriving in the early visual areas can lead to a profound degradation of recognition performance, correlating with the temporal overlap of target and mask signals in occipital cortex. Later processing stages, beyond 180 ms, seem to be unaffected by the mask.

◆ **Neocortical areas underlying mental rotation and size constancy**
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fMRI was used to investigate BOLD responses in the human cortex evoked during a mental rotation task (Metzler and Shepard, 1971 *Science* **171** 701–703). Imaging was performed with a 1.5 T whole-body Siemens Magnetom (Vision). Twenty-four 4 mm planes, positioned obliquely to the axial plane, were imaged every 10 s in a T2*-weighted sequence. The stimuli were generated off-line. Each trial consisted of two stimuli presented sequentially for 500 ms (ISI = 1 s). Each stimulus was followed by a random-dot mask (300 ms). Four conditions were conducted: passive baseline (BL, fixation point and mask only), mental rotation (MR), size constancy (SC), and pattern discrimination (PD, object pairs no rotation). Subjects responded in a 2AFC (same-different object) by a button-press. Twelve subjects participated in a training and MRI session. Rotations along the z-axis led to the best performance ($d' > 1.3$), followed by rotations along the x-axes and y-axes ($d' < 0.8$). Performance in the SC and PD tasks was good ($d' = 2.8$ and 4.2). The BOLD responses were found in occipital, occipito-temporal, parietal, and the prefrontal cortex. The results of the MR–PD comparisons indicated that the posterior parietal cortex was more activated during the MR task.
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◆ **Mental rotation vs invariant features in object perception from different viewpoints: an fMRI study**
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Object recognition can be either viewpoint-dependent (eg Tarr, 1995 *Psychonomic Bulletin & Review* **2** 55–82) or viewpoint-independent (eg Biederman and Gerhardstein, 1993 *Journal of Experimental Psychology: Human Perception and Performance* **19** 1162–1182). Our goal was to disentangle, on the behavioural and neurofunctional level, two recognition processes associated with these two routes: mental rotation and the use of viewpoint-invariant features. Two sets of 3-D block figures were created that either differed in handedness (original vs mirrored) or in the angles joining the block components (right vs skewed). Reaction times on a same–different judgement task were dependent on the viewpoint in the rotation condition (original vs mirrored), but not in the invariance condition (right vs skewed). Subsequently, six subjects participated in an fMRI experiment using BOLD contrast while presented with both conditions in alternating blocks. Results indicated that all cortical areas activated in the invariance condition were also activated in the rotation condition. However, for mental rotation, parietal areas were more activated than occipito-temporal areas. In the invariance condition, this pattern reversed. In addition, some areas were activated uniquely by the rotation condition, probably reflecting the additional processes apparent in the behavioural response patterns (ie the pure 'mental rotation' process).

◆ **Functional neuroanatomy of object categorisation at different levels of abstraction**
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Six healthy subjects participated in an fMRI experiment using BOLD contrast, while performing three tasks: (1) determining whether two successively presented nonsense shapes had the same global orientation (baseline task), (2) determining whether two successively presented natural objects belonged to the same basic level category, and (3) determining whether two successively presented objects represented the same exemplar of a category. Additionally, we manipulated the quality of stimulus presentation by degrading the stimuli in half of the trials by locally shifting the pixels constituting the lines of the figures. Both experimental tasks were associated with activations in the occipitotemporal and parietal cortex. There was no consistent difference between the two experimental tasks across subjects. Activation in an anterior focus in the fusiform gyrus (similar to the most anterior occipitotemporal activation foci in the task comparisons) was reduced when shape information was degraded, even in the baseline task. This suggests that even regions in the highest-order visual areas that are activated by the categorisation of stimuli are also activated by the bottom-up processing of shape.

IMAGING, PHYSIOLOGICAL, AND CLINICAL STUDIES II

◆ **Integration of location and colour in prefrontal cortex**

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Prefrontal neurons have spatially selective activity prior to movement onset in delayed-saccade tasks. Our goal was to determine whether delay activity is evoked by non-spatial cues such as colour. Two monkeys made saccades to one of two stimuli presented simultaneously on a CRT monitor. The animal was cued for either the location or colour of the correct target on each trial. Neuronal activity in the FEF and adjacent cortex was recorded while eye movements were measured with a search coil. 56/103 cells (54%) showed spatially selective delay activity ($p < 0.01$) when tested with the location-cue task. 6/85 cells (7%) showed significant colour-selective activity during the delay with the colour-cue task. When the task was modified so that the colour of the cue could be used to infer the location of the target during the delay interval, 36/81 cells (44%) showed significant spatially selective delay activity. The FEF appears to have primarily a spatial representation as judged by the spatial tuning of visual, motor, and memory-related signals. Colour selectivity is rare and weak. However, cells with spatially selective delay activity can be activated when colour signals the location of a saccade target.

◆ **Delayed maturation of the ventral visual stream in humans**

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Phylo- and ontogenetic pressures have structured the development of neuroanatomical circuits participating in visual information processing. For example, visuomotor control requires very early commitment of subservient brain structures. Slower maturation, more flexibility, and later commitment might be permitted, or even favoured in other cases, such as in environmentally cued classification of objects and events (see Kozma et al, 1997 *Perception* **26** Supplement, 116). We present a quantitative analysis of J L Conel's data on human cortical development in order to investigate the possibility of a protracted development of ventral visual stream function. The neuroanatomical data are based on the numbers of neurons, and myelination densities in each cortical layer under 1 mm^2 of cortical surface for 6 cytoarchitectural areas for 8 postnatal age points from birth to 72 months (fully described data: Shankle et al, 1998 *Journal of Theoretical Biology* **191** 115–140). Myelinated axonal densities show non-zero values at earlier age-points in the dorsal areas. While average neuronal numbers change at the same speed across the analysed areas, a rank-order analysis of neuronal number percortical layer reveals that dorsal areas increase neuronal numbers in layers 6 and 3 at earlier times than ventral areas. This indicates a later development of long-distance connectivity in the ventral areas.

◆ **VEPs to luminance-contrast stimuli in the attended portion of the visual field have shorter latencies**

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Psychophysical studies indicate that attention modifies the quality and the speed of visual processing of stimuli located in a selected portion of space. Previous studies with evoked potentials show enhancement of responses to attended stimuli, but no modification of latencies. If attention is a system for providing priority for action, we expect that priority is based, at least in part, on variation in the processing speed of inputs from cued locations. Thus, we expect the VEP latency to attended stimuli to be shorter than that to stimuli in the unattended portion of the visual field. In addition, we tested the hypothesis that such a priority mechanism relies on the fast-transmission magnocellular system. Luminance or colour contrast gratings were used to maximize the activation of magnocellular or parvocellular pathways. For luminance stimuli, both latency and amplitude of VEPs were modified by attention. On the other hand, for colour gratings, attention affected only the amplitude, not the latency. Spatial attention uses different mechanisms when magno or parvo systems are preferentially involved. In both cases visual responses are enhanced, but priority to stimuli in the selected space is present only for the fast-transmission magnocellular pathway.

◆ **Different responses of magno and parvo systems to sinusoidal gratings in noise backgrounds**
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It is known that different VEP components can reflect individual responses of magno and parvo systems. The aim of this work was to investigate the effect on the VEPs of external noise added to the sinusoidal gratings. VEPs were recorded from occipital lobe to appearing/disappearing six sinusoidal gratings (ranging from 0.4 to 13 cycles deg^{-1}) with a temporal frequency of 1 Hz. Dependence of VEP amplitude on the contrast of the gratings and noise was analysed. We could also vary the spatial-frequency spectrum of the noise. Comparative component analysis of VEPs to gratings presented on a uniform background or on a noise background yielded the following results: (i) Dependence of the positive VEP component P1a with a latency of 100 ms on the spatial frequency of the test gratings is not changed in the presence of additive noise. (ii) Addition of noise strongly decreases the amplitude of VEP positive component P1b (140 ms) and negative component N1 (80–100 ms). (iii) The late negative wave N2 (180 ms) increases when gratings are presented on a noise background. The data are discussed from the viewpoint that external noise affects in different ways the performance of human magno and parvo systems.

◆ **Temporal integration effect on evoked potential latency and reaction time**
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A comparison of human visually-evoked-potential (VEP) latencies and reaction time (RT) (Mihaylova et al, 1999 *Vision Research* **39** 699–705) revealed a delay of central origin in the RT to gratings of high spatial frequency (SF) in addition to the peripheral one. In the present work, we studied the contribution of temporal integration to the peripheral and central RT delay at different SFs. VEPs and RTs were simultaneously recorded to the onset of sinusoidal gratings at 0.5, 5, and 12 cycles deg^{-1}. Stimulus contrast was 20%, 30%, or 50%, and two stimulus durations were used: 10 and 100 ms. Decreasing stimulus duration from 100 to 10 ms did not affect the latencies of the early VEP wave and the RT at 0.5 and 5 cycles deg^{-1} but strongly increased RT to 12 cycles deg^{-1} (with two exceptions at the highest contrast level). The observed difference in stimulus duration effect on VEP latency and RT suggests that the central RT delay at high SF, observed by us earlier, involves stimulus temporal integration.

◆ **Temporal selective attention: behavioural and electrophysiological correlates**
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Attending to a spatial location (a spatial expectancy) influences the detectability of visual stimuli at that location. Using behavioural and electrophysiological (ERP) measurements, we examined the behavioural and neural correlates of temporal expectancies. In two tasks, brief central cues indicated the length of the interval between cue and target. The target consisted of the brief brightening of a central circle and appeared at the predicted interval 80% of the time (valid trials). In the detection task, subjects responded to the appearance of each target. In the discrimination task, subjects made different responses according to the presence/absence of a small gap in the target. Both detection and discrimination were enhanced on valid trials. EEG was recorded from 54 electrode sites (250 Hz, 0.03–100 Hz filter). ERPs were constructed for different target (valid/invalid) and cue (long/short interval) types. Modulations of target ERPs started after the visual components (~200 ms), and consisted of more positive-going ERPs to valid targets. ERPs to cues differed according to the predicted time interval. The differences reflected the engagement of multiple processes, as indexed by the modulation of potentials that have been linked to stimulus expectancy and response preparation.

◆ **Visual recognition of item-colour associations in amnesic patients and controls**
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Visual memory of an event requires encoding of individual components, as well as an ability to associate these components with each other. An influential view of amnesia is that it represents a deficit in the ability to form new associations (Aggleton and Brown, 1999 *Behavioural and Brain Sciences* **22** 425–489). We investigated item-colour associations in amnesic patients and controls. Subjects studied 24 coloured line drawings. At test, half the drawings were shown in the same

colour as at study, and half were shown in a different colour. Subjects were asked to indicate (i) whether they had seen each drawing before, regardless of the colour, and (ii) whether the drawing was the same colour as at study. Patients were given increased opportunity for study. Results showed that, despite equivalent levels of item recognition, patients were impaired relative to controls at colour discrimination. This is consistent with the view that amnesic patients are impaired in their ability to form an association between an item and its colour. However, both patients and controls showed significantly better item recognition for drawings when they were presented in the same colour at study and test. This suggests that amnesic patients can show normal implicit memory for associations despite impaired explicit memory.

◆ **Effect of contour deletion on the responses of inferior temporal neurons**
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Complementary pairs of contour-deleted shapes (CD1-2) prime each other as they prime themselves. Furthermore, humans can recognise CD drawings in which the geons are recoverable (RE) but they cannot recognise them when the geons are nonrecoverable (NRE). Are these perceptual phenomena correlated with response properties of inferior temporal (IT) neurons of macaques? Line drawings (LD) and CD1-2 or RE/NRE versions of the same shapes were presented to a fixating monkey, while extracellular single-cell activity ($n = 86$) was recorded from IT. Most of the neurons responding to LD also responded to the CD versions. Firing rates were, substantially lower for CD1-2 and RE/NRE, reflecting, perhaps, the lowered identifiability of those stimuli. Neurons responding selectively to LDs showed slightly different selectivity for CDs and RE/NRE versions. There was no difference, however, between the selectivity of CD1-2, reflecting probably their behavioural equivalence. Selectivity tunings of LD and RE were similar, but they were different from that of NRE. Thus, in monkeys, contour deletion has far more potent effects on IT cell activation than is evident from the modest increase in difficulty and equivalent priming that humans manifest when identifying such images.
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SPACE, SHAPE, AND DEPTH

◆ **Pappus in optical space**
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Observers commit systematic errors when estimating geometrical properties from a fixed vantage point. Research has conventionally focused upon the metric structure, neglecting more fundamental geometrical structures. We address the projective instead of the metric structure of visual space. We did experiments in the field under full cue conditions. Only location was constrained, head movements, twists in the waist, and turning on the feet being allowed. Observers visually manoeuvred a radio-controlled vehicle from a fixed vantage point to a target 2–24 m away in the field. The target was implicitly defined as the intersection of two (visually) straight lines. These again were implicitly defined through a pair of stakes in the ground. We focused on Pappus's theorem [see almost any popular textbook on elementary geometry, for instance Morris Kline, 1972 *Mathematical Thought from Ancient to Modern Times* (Oxford: Oxford University Press)], which is a theorem for the Euclidean plane but is conventionally taken as an axiom in the theory of the projective plane. We report here that Pappus's condition is empirically satisfied for the visual ground plane.

◆ **Distance perception mediated through nested contact relations among surfaces**
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There is now substantial evidence that, as hypothesised by Alhazen, and later by Gibson, distances are often perceived in reference to a common surface such as the ground. In complex natural scenes, however, objects do not necessarily share a common surface. Nevertheless, they usually can be related to each other through a series of contact relations among adjoining surfaces. Our research was designed to find out how well human observers, under monocular static viewing conditions, are able to utilise these nested contact relations in distance perception. We presented

computer-generated naturalistic scenes of a cube resting on a platform, which in turn was resting on the ground. Observers adjusted a marker on the ground to equal the perceived distance of the cube. We found that: (i) perceived distance of the cube varies appropriately as the perceived location of contact between the platform and the ground varies, (ii) variability increases systematically as the relating surfaces move apart; (iii) precision is preserved, however, when certain local edge alignments are present. These results demonstrate considerable efficiency in the mediation of perceived distance through a series of contact relations among surfaces. We are now investigating different pathways through which distance information may propagate in more complex situations.

◆ **What natural textures convey 3-D shape?**
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Li and Zaidi (*Vision Research* in press) used synthetic texture patterns on a corrugated surface to show that 3-D shape is only conveyed when the retinal image contains visible energy along projected lines of maximum curvature on the surface. This pattern of energy arises from visible energy in the pre-corrugated pattern in the direction along which the surface is to be maximally curved. The oriented energy is visible in the pre-corrugated pattern if it is dominant or discrete in the amplitude spectrum. To see if this rule generalises to natural textures, we computed the amplitude spectra of the Brodatz collection [1966 *Textures: A Photographic Album for Artists and Designers* (New York: Dover)]. Each pattern was then corrugated in depth and projected in perspective onto an image plane. The perceived shape of the surface was reconstructed from a series of local depth estimates between pairs of central locations on the surface. The results showed that only those textures containing dominant or discrete energy along the direction of maximum curvature ($\sim 40\%$ of the patterns) conveyed veridical shape. For the remaining patterns, most of which were isotropic, observers could not distinguish between concave and convex shapes.

◆ **An analysis of several stereoscopic illusions**
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There are several stereoscopic phenomena in which the perceived slant or curvature does not correspond to the disparities. These illusions include Craik–O'Brien, staircase, slant and curvature contrast, and the effects of reference frames. I present a theory of these illusions. The theory is based on an analysis of the signals presented by these stimuli. The final slant, curvature, or depth estimate is a weighted combination of stereoscopic and nonstereoscopic estimates. The weights are proportional to the statistical reliabilities of the individual estimates. In the above-mentioned illusions, nonstereo signals (texture gradient, outline shape) specify a frontal plane and stereo signals specify different depth relationships. The stimuli are called illusions because the final percept is in some way inconsistent with the stereoscopic signals. The theory predicts the illusory percepts. The key elements to predicting the illusions are the conflicts between stereo and nonstereo signals, and the greater reliability of high as opposed to low disparity gradients. Eliminating the stereo–nonstereo conflicts or altering the disparity gradients causes significant reductions in the magnitude of the illusions. In summary, these stereoscopic illusions are a byproduct of the visual system's attempt to reconcile conflicting information in a statistically sensible fashion.

◆ **Comparing the resolution of extra-retinal information about distance and direction**
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When judging an object's position relative to ourselves, we are better at judging its direction than its distance. Is the reason for this purely geometrical, or do we have more reliable information about our direction of gaze than about our ocular convergence? We asked subjects to align two vertical lines (length 1.9 deg; vertical separation 9.1 deg) both laterally and in depth. To force them to use extra-retinal information to perform the task, the two lines were never shown simultaneously. Subjects determined which was visible by directing their gaze at it; the switch took place during the vertical saccade between the targets. When expressed as distances, the standard deviations of the settings were more than 10 times larger in depth than laterally. When expressed in terms of the target's angle with respect to each eye, the standard deviations were very similar for vergence and version. We conclude that the resolution of extra-retinal information about the orientation of our eyes is no different for distance and direction. The difference in accuracy arises when eye orientation is translated into physical distance, or when the subject's performance is influenced by factors other than the resolution of eye orientation.

◆ **On the birth of perspective**
C W Tyler (Smith-Kettlewell Eye Research Institute, 2318 Fillmore Street, San Francisco, CA 94115, USA; fax: +1 415 345 8455; e-mail:cwt@ski.org)

Linear perspective as a representation of space is generally attributed to Brunelleschi, and codified by Alberti (1435 – 1436), during the Renaissance. Nevertheless, the core construction of 'central' perspective, based on a single central vanishing point, was widespread some 1500 years earlier in Rome and Pompei (presumably by Greek artists). The principle was explicitly described at the time by Vitruvius, the Roman architect. In the Renaissance, the projection geometry of receding horizontals emerged as Alberti's 'construzione legittima'. But this construction was essentially implemented by Pietro Lorenzetti, about a century earlier, implying a progressive development of the ideas. The intense interest in extant Roman architecture during the 14th and 15th centuries raises the question of whether some of the concepts of perspective might have been transmitted from Roman times. Strict linear perspective may be codified into eight rules of perspective representation. A significant proportion of Dutch and Italian Renaissance paintings violate one or other of these rules, even including some manuals on perspective. Some of the violations were arguably introduced for dramatic effect or as a compromise for multiple viewing positions, but many seem to reveal incomplete knowledge of perspective. Particular weaknesses were the treatment of oblique objects, and decentration of the principal vanishing point.

OPTIC FLOW

◆ **Vection depends on an interaction between retinal and extra-retinal factors**
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We challenge the traditional view that smooth retinal image motion of a large pattern (optokinetic stimulus, OP) suffices to induce sensations of self-motion (vection). Stationary subjects were presented with three concurrent stimuli: an OP, a fixation point (FP) for ocular fixation or pursuit (both projected on a semicircular screen), and a dark window frame close to the eyes. The frame created visual field boundaries (VFBs), similar to the normal retinal shadows of the ocular orbits, which could move independently from eye movements. Each stimulus either remained stationary or moved horizontally and sinusoidally (0.05 Hz) around the subject's head. When they moved they did so in temporal synchrony. The results from 10 conditions (combinations of stationary or moving stimuli) showed that, contrary to traditional wisdom, retinal OP image flow is not crucial for vection. Instead, for vection to develop there must be at least one non-zero retinal motion signal—either from the OP image, or from the VFB shadows—unequal to ocular velocity (ie efference copy). Stated differently: vection does not happen if during an eye movement there is no relative motion on the retinae between the OP image and the VFB shadows.

◆ **Estimating time-to-contact from complex retinal flow**
C D Giachritsis, M G Harris (Cognitive Science Research Centre, Department of Psychology, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK; fax: +44 121 414 4897; e-mail: giachric@psychol.bham.ac.uk)

Observers estimate time-to-contact (TTC) from the expanding retinal flow generated by their translation through the world. We have previously shown that observers use the rate at which clusters of dots move apart [global expansion (GE)] rather than the rate at which they expand [local expansion (LE)] to estimate TTC. However, adding rotation to the flow destructs the GE but leaves LE intact. Under these circumstances observers could base their TTC estimates on LE since this kind of information is immediately available. In the present study, observers estimated the absolute TTC of stimuli containing GE and LE of clusters of dots with rotations up to 30° s^{-1}. It was found that increasing LE by a factor of 16 (ie the relative TTC of the cluster varied from 4 to 0.25) decreased the slope only by a factor of 2.5 (from 0.4 to 1) and decreased the intercept by a factor of 7 (from −0.5 to 2.5 s). We concluded that, even with complex flows where LE remains unaffected, observers try to make use of GE in order to estimate TTC.

◆ **A statistical process model of movement-in-depth detection**
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Movement-in-depth (MID) detection is generally accurately modeled with Weber ratios. However, these models fail to explain the effects of exposure time, ISIs, or changes in detection times (DTs) due to the particular MID profile in continuous-exposure trials. We hypothesise that these effects are the result of two interacting processes: noise integration and forgetting. An observer's

internal representation of an object's visual angle, modeled as a distribution function, narrows with exposure owing to noise integration and widens owing to forgetting. The model statistically compares this representation against one derived from observation to generate a cumulative distribution function of DTs. We derived the shapes of these internal representations and the time constants of these processes experimentally using a 2AFC discrimination task. The model accurately predicts the distribution (mean and variance) of MID DTs for a range of conditions in which a disk of a given size (0.5 to 5 deg) is displayed for a given exposure time, then moves in depth (while displayed) with a given constant angular velocity or acceleration. We tested from pure reaction times to 7 s DTs. The ability of the model to predict the effects of optic flow on MID detection guides future research.

◆ **The role of lifetime, velocity, and perspective cues in the perception of radial flow fields**
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Locomotion in the *z*-direction through the environment produces visual stimuli which are known as radial flow fields. Information contained in these flow fields is used to guide locomotion and balance adjustments. The role of the many parameters determining the flow fields is still little understood. We studied flow fields made of random elements that varied in lifetime, velocity and perspective cues. Elements moved along radial paths with appropriate acceleration. Thresholds for expansion/contraction were determined by varying the amount of coherent motion. Elements could traverse the whole display (infinite lifetime) or existed only for two instances (minimum lifetime). Velocity was varied by a factor of four. Size and shape (perspective cues) of the elements could either be a constant small spot or parallelograms changing according to distance from the centre. Judgments were very accurate for infinite lifetime, but short lifetime introduced a large bias in favour of expansion. Perspective cues improved threshold only for short lifetime. Thresholds for short lifetime were four times higher than for infinite lifetime. Speed had an effect only for infinite lifetime. Similar results were also found for a sensitivity measure. These results demonstrate important aspects of the spatial and temporal integration of the mechanisms underlying the perception of radial flow fields.

TUESDAY

SYMPOSIUM

ARTICULATION AND LIGHTNESS PERCEPTION

◆ **Articulation of achromatic scenes**

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Achromatic articulation is the addition of incremental and decremental surfaces within a scene that preserve its space-average luminance. Articulation strengthens the inference of an illumination difference between surrounds of different mean luminances. In the current simultaneous-contrast experiment, articulation was defined as the introduction of several 2 deg × 2 deg square incremental and decremental patches within each of two 10 deg × 10 deg square surrounds while preserving their space-average luminance on a CRT. The number of articulation patches ranged from a minimum of 4 per surround to 20 per surround in which case the stimulus appeared like a complex Mondrian. A 1.25 deg × 1.25 deg square comparison patch, centred within the brighter surround, was set by the experimenter, while a 1.25 deg × 1.25 deg square test patch, centred within the dimmer surround, was set by the observer to match the comparison patch in either brightness or lightness. Brightness judgments made on articulated surrounds diverge further away from a physical luminance match toward a ratio match compared to unarticulated (ie homogeneous) surrounds. Likewise, lightness judgments made on articulated surrounds approach colour constancy compared to unarticulated surrounds. Thus, articulation strengthens the inference that a global luminance edge between surrounds in an achromatic simultaneous-contrast experiment is due to a change in illumination rather than reflectance.

◆ **Articulation and scene statistics**

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A scene in the world contains surfaces of various reflectances, and the optics of the scene (notably the illumination level) determine how reflectance is mapped to luminance. One may term this mapping the atmospheric transfer function (ATF). Lightness perception involves an inverse mapping: estimating reflectance given luminance; it may be described in terms of a lightness transfer function (LTF). The LTF will vary from point to point in an image, depending on the local and global properties of the image. We can think of the LTF as a statistical estimator based on the observed image statistics in combination with prior knowledge of the statistics of scenes and atmospheres. For a given image, more samples can lead to more reliable estimates. I propose that increased articulation in an image may serve the function of increasing the apparent number of samples, thereby increasing the visual system's confidence in its local estimate of LTF. This can lead to greater lightness constancy and stronger lightness illusions.

◆ **Luminance gradients and colour appearance**

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Investigations of luminance-gradient effects can be classified into two lines of research. The first explores the direct effects of luminance gradients on colour appearance, while the second explores how the colours of surfaces are indirectly influenced by other surfaces that are directly affected by luminance gradients. Studies of direct luminance-gradient effects concentrate on the role of shaded edges on the perception of shadows, on colour and texture appearance, and on phenomenal glare. Studies of indirect luminance-gradient effects focus on how the spatial arrangement of luminance gradients affects lightness and brightness, and can be classified in two ways. One is primarily concerned with understanding and modelling the perceptual mechanisms that determine colour appearance by manipulating different kinds of luminance gradients. The other is mainly concerned with the relationship between luminance gradients and perceived illumination measured by judging lightness and brightness as a function of articulation and the spatial organisation of luminance gradients. New experimental evidence in constancy-type conditions provide additional evidence that luminance gradients play an important role in the perception of illumination even with conflicting edge information.

◆ **Colour constancy in the Mondrian world: illuminant adjustment under varying image surfaces**

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Previous colour-constancy studies have shown that the colour of a test surface varies as a function of both the illumination and the image surfaces. I investigated to what extent the

same illuminant change induces the same illuminant adjustment under varying image surfaces. Both illuminant changes that occur within the image (simultaneous colour constancy) and illuminant changes that occur across images (successive colour constancy) were examined. When investigating successive colour constancy, subjects were presented with CRT simulations of uniformly illuminated surfaces (Mondrians) and, for a number of illuminants and surface collections, adjusted a test light so that it had a certain colour appearance. When investigating simultaneous colour constancy, subjects saw CRT simulations of two identical surface collections side by side which were differently illuminated. Subjects set matches for several surface collections, both appearance and surface colour matches. In both types of situations and for both types of colour matches, the settings revealed effects of illumination and image surfaces. Although the illuminant adjustment varied with image surfaces, the amount of variation was small. These results indicate that, at least in the situations employed, image surfaces play only a minor role for the illuminant adjustment of our visual system.

◆ **When does increased chromatic variability enhance colour constancy?**

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Retinotopic processes, such as lateral inhibition and chromatic adaptation, are assumed to play an important role in mediating colour constancy. The influence of lateral inhibition on appearance matching has been shown to extend up to about 1.5 deg. Indeed, in the absence of eye movements, chromatic variation that is removed further away from the surface of interest does not appear to exhibit any influence on appearance matching. Within the local surround, spatially weighted linear averaging of the chromatic variation appears to govern the magnitude of the lateral interactions. Eye movements, such as made during most natural viewing conditions, will mediate longer-range spatial interactions by influencing chromatic adaptation. To the extent that adaptation is to the temporal average of the illuminant, colour constancy is enhanced. When additional information beyond that provided by the retinal image is used, such as when there are objects of which the colour is known within the scene, when informed that colour differences are due to the illumination (surface or 'paper' matches), when the average reflectance is assumed to be neutral (grey-world hypothesis), or when the configuration suggests a particular illumination (eg when there are surfaces with different orientations), chromatic variation will exhibit additional influences.

◆ **Relational colour constancy in colorimetrically extreme images**

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Relational colour constancy refers to the constancy of perceived relations between surface colours under changes in the spectral content of the illumination. This constancy may be based on the computation of spatial ratios of cone excitations due to light reflected from articulated surfaces. In that activity need take place only within cone pathways, relational colour constancy might be assumed to be a form of lightness constancy. This hypothesis was tested in a psychophysical experiment with colorimetrically extreme images: isoluminant, achromatic, and, as a control, unconstrained. Pairs of computer-generated images of illuminated Mondrian patterns were presented in sequence in a two-interval forced-choice design: in one interval, image pairs were related by an illuminant change; in the other, by a nonilluminant change. Observers had to identify which was which. They reliably discriminated illuminant from nonilluminant changes with all three image types. Relational colour constancy is thus different from lightness constancy. Computer simulation showed that performance could be predicted from spatial ratios of cone excitations or from spatial ratios of non-opponent and opponent combinations of cone excitations. Relational colour-constancy seems not to be restricted to activity within either luminance or chromaticity pathways alone.

◆ **Articulation and the strength of frameworks**

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According to David Katz, the greater the articulation (roughly the number of elements) within a field of illumination, the greater the lightness constancy. This concept has been almost totally forgotten, despite an abundance of empirical evidence, both older and recent. Recent evidence shows that lightness values depend on articulation level in simultaneous lightness contrast,

White's illusion, reverse contrast, the Benary effect, Adelson's corrugated Mondrian, staircase Gelb effect, and experiments on lightness constancy and on depth and lightness. This evidence suggests two modifications of the Katz formulation: (i) The greater the articulation within a framework, the more strongly surfaces are anchoring within it. (ii) A framework should be defined as a perceptual group, not simply as a region of illumination. These findings strongly undermine two popular approaches to lightness: contrast theories and intrinsic image models. Changes in articulation level can change perceived lightness without changing either the conditions of lateral inhibition or the conditions for edge classification and integration. The graded effect of articulation level on lightness suggests that lightness is not computed in a global, structure-blind manner, nor is it computed exclusively within illumination frames of reference.

◆ **Is lightness induction a pictorial illusion? A defense of a Helmholtzian explanation**
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Helmholtz believed that lightness induction originates from an error in judgment of apparent illumination. His theory implicitly suggests an invariant relationship between lightness and apparent illumination (shadow). It has been criticised on the grounds that (i) lightness–shadow invariance has not always been experimentally confirmed; and (ii) it predicts much stronger lightness induction than is usually observed. However, a critical analysis of the literature shows that research has failed to verify the lightness–shadow invariance, judging either brightness or the direct illumination from the light source, rather than apparent illumination at the object surface. I also present a demonstration of Adelson's wall of blocks with vertical luminance gradients which show that lightness induction can be much stronger than once thought. However, 3-D version of the same wall of blocks, made of cardboard, induces no lightness illusion at all, despite producing the same illuminance distribution on the retina. Thus, I argue that lightness induction is probably a phenomenon of pictorial rather than natural vision. I believe that the Helmholtzian explanation is still valid but only for pictorial displays, where lightness induction is produced by what we call shadow-compatible luminance distributions. These distributions inappropriately provoke the mechanism that underlies lightness–shadow invariance since other visual cues can only guarantee veridicality of the perception of illumination but not that of lightness.

◆ **'Discounting the illuminant': What it means, how to do it**
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The initial data about surface colours in a scene, photoreceptor excitations, depend on the spectral properties of both the illumination of the scene and the surfaces present. A visual system that assigns stable colours to surfaces despite changes in illuminant must, in effect, discount the effect of the illuminant change during postretinal colour processing. Such a 'colour constant' visual system comprises a repertoire of possible adaptational states that can cancel possible illuminant changes. Following a change in illumination, the visual system must correctly change adaptation state to cancel the illuminant change. A failure of colour constancy may occur because the adaptational repertoire of the visual system is inadequate to cancel a given change in illumination, or because the adaptational state changes to an incorrect state. We first characterise the range of adaptational states needed to discount illuminant changes in a realistic environment, on the basis of recent, large samples of measurements of daylight and biochrome surfaces (leaves, flowers). We compare this repertoire to classical models of chromatic adaptation (eg von Kries). Last, we recast the second problem, how to select the correct adaptational state from the repertoire, in terms of explicit cues to the illuminant and their combination.
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◆ **A role of perceptual organisation in colour perception**
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Colour matches between two small patches were made in a display with ten larger regions of various chromaticities. The spatial arrangement of the ten regions was varied while keeping constant their chromaticities and sizes. Further, the immediate surround of each patch was held fixed to avoid changes of contrast at the patch border. The aim was to vary the perceptual grouping of the ten regions and the patches, by making minimal changes to the spatial configuration of the lights in view. At the most basic level, the results show that colour perception cannot be explained fully from knowing all the chromaticities in view. Their relative positions must also be considered. Further, the spatial configurations differed only with respect to light some distance

from the patches, so the measurements reveal the influence of chromatic context. We interpret the experiments in terms of perceptual grouping of regions inferred to share a common illuminant. This grouping is a fundamental aspect of any colour-constancy theory that takes account of illumination.

◆ **Measurements of object and illuminant identification**
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Can observers identify similar objects under different illuminants despite changes in appearance, and how do they do it? For sets of everyday objects, a shift between natural illuminants leads to a translation of all $L/(L+M)$ chromaticities by a constant, and multiplication of all $S/(L+M)$ chromaticities by a constant. The general form of these transformations can be considered an invariant, and has been used successfully as a heuristic in object identification algorithms (Zaidi, 1998 *Journal of the Optical Society of America A* **15** 1767–1776). How good are observers at exploiting these physical invariants? We use forced-choice methods to measure observers' abilities to identify sets of objects within and across illuminants and illuminants within and across sets of objects, and to identify objects in different spatial configurations of the same set across illuminants. We back-project images from a large-aperture 3-CRT based projector onto a 27-inch-diameter high-gain dome. This set-up adds the experience of being immersed inside an illuminated world, while retaining computer-controlled power to provide fine-grained colour resolution, render textured objects, shift spatial configurations, and control time-courses of presentations. For objects sampled from the Vrhel et al (1994 *Color Research and Application* **19** 4–9) set, and daylight and artificial illuminants, observers' performances are compared to the performance of heuristic algorithms.

◆ **The role of cues to depth and scene articulation in colour constancy**
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To investigate the role of cues to depth and scene articulation in colour constancy, we have constructed an apparatus by which the same three-dimensional scene may be viewed (monocularly) either directly or through a telescopic viewing system (TVS). The TVS eliminates depth cues provided by motion parallax and accommodation. The subjective effect of viewing the scene through the TVS is to produce a more two-dimensional percept. Observers' achromatic loci were measured in the context of scenes composed of different surfaces under different illuminants, and the data were used to compute a colour constancy index for various viewing conditions (see Kraft and Brainard, 1999 *Proceedings of the National Academy of Sciences of the USA* **96** 307–312, for general methods). Constancy indices were obtained across two main experimental manipulations: direct vs TVS viewing and variation in the number of distinct coloured surfaces in the scene (amount of articulation). Efforts were made to match the proximal stimulus (retinal size, retinal illuminance, spectral properties) across direct and TVS viewing. Initial results (two naive observers) indicate that direct viewing leads to better colour constancy than TVS viewing and that increasing articulation improves constancy.

SYMPOSIUM

COMPARATIVE ASPECTS OF VISUAL PERCEPTION

◆ **Differential use of the right and left eye (and ear) by vertebrates other than mammals**
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One way of deducing the general specialisation of right and left hemispheres, which has been revealed in humans, is to compare lateralisation affecting different senses. This is now possible in the domestic chick for vision and hearing. Two approaches are presented: (A) the spontaneous turning of right or left eye or ear towards a stimulus; (B) the presentation of stimulus to right or left eye or ear. (A) Right eye or ear is used when a decision is being taken whether to respond or not (eg approach on first encountering an imprinting stimulus). Left eye or ear is used when confirming that a stimulus is indeed familiar. (B) First presentation of an attractive sound in right hemispace sets up a persistent preference for that sound, whereas preference in left hemispace is followed by choice based on the relative properties of the two sounds. Use of the right eye brings a relatively persistent choice (if choice occurs) based on striking dimensions (shape) or large transformations. Use of the left eye brings a rapid response to small transformations, which would only belatedly affect the bird's right eye. Comparison is made with differential eye use in other groups of vertebrates.

◆ **Acquisition of a people concept vs use of simple features**
U Aust, M Loidolt, L Huber (Institute of Zoology, University of Vienna, Althanstrasse 14, A 1090 Vienna, Austria; e-mail: ulli@Ozwei.zoo.univie.ac.at.)
We reinvestigated the findings by Herrnstein and Loveland (1964 *Science* **146** 549–551), who successfully trained pigeons to respond to the presence or absence of human beings in photographs and claimed that they had found incontrovertible evidence for the learning of a concept. Our pigeons readily learned to discriminate between pictures characterised by the presence (class P) or absence (class NP) of people and showed good transfer to novel instances of the two classes. However, we found evidence that they relied strongly on local, low-level features. When the pigeons were presented with scrambled versions of the stimuli, performance continued to be significantly correct. The importance of colour was demonstrated by a decline in the pigeons' performance on grey-scale stimuli. When humans were either presented against backgrounds from class NP stimuli, or were removed from class P stimuli, at least half of the subjects still performed correctly. Further tests were carried out to investigate the role of relevant features (eg skin colour or human shape) and irrelevant features that tend to correlate with the presence of people (eg clothes or tools). Our results argue in favour of a feature model rather than the learning of a true concept.

◆ **Visual discrimination and perception of mimicry patterns in pigeons**
W H Dittrich (Department of Psychology, University of Hertfordshire, College Lane, Hatfield AL10 8UY, UK; e-mail: w.dittrich@herts.ac.uk)
In order to build models of the evolution of mimicry, it is essential to understand the mechanisms of sensory processing and learning of the receiver. In a first study, discriminative operant conditioning methods were used to measure the similarity perceived by pigeons (*Columba livia*) between naturalistic images of wasps and various species of supposedly mimetic hoverflies, and a computer-based image-processing technique was used to measure objective similarity. The results show that pigeons rank naturalistic images of mimics according to their similarity to a wasp model. Thus pigeons behave as if many hoverflies are indeed wasp mimics. However, they rank the two commonest hoverflies as very similar to wasps, despite these looking decidedly poor mimics to the human eye. In a second study, pigeons were trained on a visual discrimination task with a novel apparatus which enabled pinned specimens of insects, illuminated by natural daylight, to be presented under a pecking key transparent to ultraviolet light. New evidence is presented on the question whether the previous findings are reliable when instead of naturalistic images the real specimen (including UV colour) are used. Finally, some constraints in the birds' perceptual and learning mechanisms are discussed in relation to the evolution of mimicry.

◆ **Minimisation of modal contours: a cross species strategy**
B Forkman, G Vallortigara¶ (Department of Zoology, University of Stockholm, Svante Arrhenius, S 106 91 Stockholm, Sweden; ¶ Department of Psychology, University of Trieste, via dell'Università 7, I 34123 Trieste, Italy; fax: +46 8 16 77 15; e-mail: bjorn.forkman@zoologi.su.se)
Two chromatically identical patterns, a diamond and a ladder, were shown on a computer touchscreen. Domestic hens were reinforced for pecking at the pattern that was the highest up on a grid providing pictorial depth information, ie the pattern that to a human appears as being the furthest away. Every tenth trial was a probe trial with the two patterns partially overlapping. In the absence of other cues, depth stratification can occur on the basis of a minimisation of interpolated occluding contours: in humans, the diamond is usually perceived to be in front of the ladder because shorter interpolated contours are needed to account for the occlusive effect of the diamond on the ladder. The hens pecked more often at the ladder during probe trials. The results suggest that the avian and mammalian visual systems operate along similar principles when dealing with the problem of solving occlusion indeterminacy in chromatically homogeneous patterns.

◆ **Head orientation and the visual control of locomotion in birds**
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Specific patterns of gaze are known to be important for the accurate control of various forms of locomotion, such as walking and driving a car, but the reasons for this are not yet understood. In particular, the relationship between the functions of gaze in visuomotor control and in foveation are not known. One approach to these problems is to study the role of gaze in visuomotor control in species with a retinal organisation different from that of primates. I have found that head orientation is correlated with flight trajectory as pigeons fly towards a landing perch, and that chicks orient their heads at an angle related to their trajectory of walking on a slope, or to the take-off trajectory of a jump across a gap. None of these patterns of behaviour can be

explained as fixation of a target of locomotion on a specialised retinal area. These findings suggest that a neural coupling between the mechanisms controlling locomotion and those controlling head and eye movements is primitive among birds, and has been adapted in the course of evolution for a variety of specialised functions, including that of sampling the retinal image with a fovea.

◆ **Squirrel monkeys can perceive subjective contours, amodal completion, and transparency**
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The aim of this study was to test whether squirrel monkeys, *Saimiri sciureus*, can perceive geometric forms under three conditions: when they are defined by subjective contours (SC) and when they appear to be occluded by an opaque surface (OC) or by a transparent surface (TP). Rhesus monkeys can perceive forms under such conditions, but squirrel monkeys have not previously been studied. Monkeys were trained on a matching-to-sample task. On each trial one of four geometric forms (the sample) appeared first, which the monkey had to touch. Following the response, four forms were presented equidistant from the sample, one of which (the matching stimulus) was similar to it. Responses made directly to the matching stimulus were rewarded. The matching stimuli appeared in cross-hatched lines of various widths and spacing. In all experiments, we used white cross-hatched lines, grey geometric forms, and a black background. In condition OC, grey forms appeared to be occluded by a pattern of opaque cross-hatched lines. In condition TP, they appeared to lie behind a pattern of transparent cross-hatched lines. In condition SC, the edges of the forms were defined by the terminations of the cross-hatched lines. Performance was measured in terms of correct responses and reaction times, and varied with the width and spacing of the cross-hatched lines. Human observers were also tested, and showed similar results to the monkeys. The results indicate that squirrel monkeys are capable of perceiving objects under these conditions in a similar way to humans.

◆ **Colour vision in domestic chicks**
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Birds have four types of single cones, which are sensitive to UV, short, medium, and long wavelengths, respectively. Experiments were designed to establish how colour is used for object recognition by domestic chicks (*Gallus gallus*). The birds were trained to obtain food from small containers printed with stimulus patterns. These patterns comprised tilings of grey (70%) and coloured (30%) rectangles whose intensities varied randomly about a given mean (contrast range 0.3). Chicks learn the colours quickly and accurately. The results indicate that all four cone types probably drive least three opponency mechanisms, as required for tetrachromatic colour vision. The spectral sensitivities of these mechanisms are not known, but one compares outputs of UV and short-wavelength receptors, one medium- and long-wavelength receptors, and a third short- against long- and/or medium-wavelength receptors. Birds trained to one coloured pattern and tested on a range of novel alternatives prefer the familiar hue and saturation, but are attracted by patterns with high luminance contrast.

◆ **Patterns of visual lateralisation in pigeons: seeing what is there and beyond**
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In pigeons, as in several other bird species, there is now good evidence for a left-hemispheric superiority in visual tasks that require the recognition and discrimination of object features. To evaluate whether the well-documented left-hemispheric dominance in visual-discrimination tasks in pigeons is also accompanied by a complementary superiority in other—eg spatial—tasks, we tested pigeons in two spatial tasks and two visual illusions. We used the technique of reversible monocular occlusion which allows us to restrict visual input to the brain hemisphere contralateral to the open eye, since the fibres of the avian optic nerve cross almost completely. Contrary to the pattern suggested for humans, we found no lateralisation of performance during a spatial-working-memory task in a maze. Furthermore, there was a clear left-hemispheric superiority in a homing task in the field. A similar pattern emerged in the study of the pigeon's susceptibility to visual illusions which are suggested to show either no lateralisation in humans or a higher susceptibility of the right hemisphere. In a task assessing the pigeon's perceiving of the herringbone illusion it turned out that the dominant (left in most individuals), but not the subdominant, hemisphere was deceived. In a study on subjective contours with Kanizsa's triangles and squares, part of the pigeons reacted to test stimuli as if they were seeing subjective contours. The pattern emerging in monocular left and monocular right tests was similar. As indicated by control tests, pigeons perceiving subjective contours were rather attending to the 'global' pattern of the stimuli while birds not perceiving

subjective contours were attending to extracted elements of the stimuli. Thus both hemispheres were capable of 'filling in' subjective contours and both hemispheres can analyse stimuli in a more 'global' or more 'local' manner. Results suggest that visual lateralisation in pigeons depends on the interplay of several components which might be lateralised to a different extent.

◆ **Discrimination of point-light animation sequences (Johansson's biological-motion displays) by newborn chicks**

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Day-old chicks were exposed to point-light animation sequences depicting a walking hen or a rotating cylinder. On subsequent free-choice test they approached the novel stimulus, irrespective of it being the hen or the cylinder. In order to obtain equivalent local-motion vectors, in another experiment 1-day-old and 2-day-old chicks were exposed to either a point-light animation sequence depicting a walking hen or to a positionally scrambled walking hen (ie an animation sequence in which exactly the same dot motions as those in the walking hen were used, only with their starting positions spatially randomised). Chicks at both ages proved able to discriminate the two animation sequences, males approaching preferentially the novel stimulus, females the familiar one. These results indicate that discrimination was not based on local-motion vectors, but rather on the temporally integrated motion sequence.

◆ **Perception of shape from shading in the chimpanzee (*Pan troglodytes*)**

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Two chimpanzees (*Pan troglodytes*) and five humans were tested for the perception of shape from shading in visual search tasks. Subjects were required to detect and touch an odd item (target) among uniform distractors. Humans found the target faster under vertical than under horizontal shading, consistent with previous research. On the other hand, both chimpanzees showed the opposite result, finding the target faster under horizontal shading. These results were replicated in texture-segregation tasks. This species difference could not be explained by head rotation or head shift parallel to the surface of the monitor. Furthermore, when the contour shape was changed from circle to square, or the shading type was changed from linear to stepwise, the difference in performance between vertical and horizontal shading disappeared in chimpanzees, while humans still showed a difference between shading directions. These results suggest that chimpanzees process shading information in a different way from humans.

◆ **Unusual view test in pigeons**

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We can recognise solid objects from unfamiliar visual angles. This viewpoint invariance is considered to indicate higher visual function. Pigeons showed viewpoint invariance for still video images of familiar objects, such as a home cage feeder, but not for those of unfamiliar objects, such as a coffee cup. When wooden blocks were placed in their home cages to make the pigeons familiar with these objects, the birds showed viewpoint invariance for the video images of these objects. Here I show that experience with solid objects from a fixed angle does not result in viewpoint invariance. Pigeons were trained to discriminate a cone and a ball. After the birds learned the discrimination, cones and balls of different size, different orientation, or partly occluded were presented as test stimuli. The pigeons showed size invariance but not orientation invariance. These results suggest that pigeons need experience with solid objects from different viewpoints to acquire viewpoint invariance.

◆ **Perception of biological motion by newly hatched chicks and quail**

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We investigated whether chicks and quail recognised the biological motion of their species by testing their potential for imprinting stimuli. Newly hatched chicks and quail were imprinted by one of the following video clips: the canonical biological motion (BM) of an adult fowl, that of an adult quail, inverted BM, a parallel motion of point-lights, randomised motion of point-lights, or the BM of other species. In experiment 1, we examined whether the subjects were imprinted more strongly with canonical BM than with the parallel motion of point-lights,

inverted BM, or the randomised motion of point-lights. A significant preference was shown by chicks and quail only under the condition in which the imprinted stimulus was the canonical BM and the novel stimulus was the parallel motion of point-lights. In experiment 2, we examined whether the subjects were imprinted more strongly with the canonical BM of their own species than with that of the other species. The condition in which the imprinted stimulus was the BM of a human and the novel stimulus was the BM of their own species showed significant positive preference in chicks and significant negative preference in quail.

ORAL PRESENTATIONS

MOTION INTEGRATION I

◆ **Stronger motion signals from grouped isoluminant colour gratings than luminance-defined gratings revealed in motion capture**

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A colour-defined isoluminant object is induced to move by the motion of a luminance-defined object [Ramachandran, 1987 *Nature (London)* **328** 645–647)]. The most common explanation for this motion capture is that a weaker motion/location signal from a chromatic edge is overridden by a stronger signal from a luminance-defined edge. However, we found that the motion direction of a colour-defined isoluminant grating is more strongly influenced by the motion of flanking isoluminant gratings than by flanking luminance-defined gratings. Five gratings were presented moving in square apertures. An isoluminant colour grating was flanked by top, bottom, right, and left gratings. In half of the trials, the top and bottom gratings were isoluminant while the left and right gratings were luminance-defined. In the other half, the arrangement was reversed. The contrast of the luminance-defined gratings was varied from trial to trial. In each trial, subjects had to judge in which of the vertical or horizontal directions the central grating moved. The results show that, with a wide range of luminance contrasts, the central grating appeared to move in the direction along the isoluminant flanks. This suggests that motion signals from the isoluminant gratings, perhaps grouped by similarity, are stronger than signals from luminance-defined gratings.

◆ **Are moving objects processed faster than flashes?**

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It has been suggested that motion is processed faster than other features. According to this view, the flash-lag effect (a flashed item appearing to spatially lag a moving item) can be explained by moving items being processed faster than flashed items. We test the 'latency-difference' hypothesis. The sudden, simultaneous, appearance of a moving and a flashed item produces a strong flash-lag effect [Khurana and Nijhawan, 1995 *Nature (London)* **378** 565–566]. To see if this effect can be accounted for by the faster processing of motion, we devised two tasks. In a reaction-time task, observers pressed a key to the onset of either a moving or flashed item. In a temporal-order-judgment task, observers indicated which item appeared first (2-alternative forced choice). If motion is processed faster, then observers should (i) respond more quickly to the moving item, and (ii) report the earlier appearance of the moving item relative to the flashed item. Neither of these predictions was confirmed. Our findings contradict the latency-difference hypothesis. However, the results can be explained by the alternative account of the flash-lag effect in terms of correction in the space domain for moving objects [Nijhawan, 1994 *Nature (London)* **370** 256–257].

◆ **The bigger they are the slower they move: the effects of field size on speed discrimination**

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Speed match and speed discrimination thresholds were measured as a function of the field size for a grating pattern (1 cycle deg^{-1}, 2 Hz). All procedures used brief duration (250 ms) stimuli and 2AFC decisions. As the diameter of a standard grating increased over a four-fold range, the speed match for the test grating decreased, indicating the larger patterns appear to move slower. Does this perceived slowing affect discrimination thresholds? When the two patterns to be compared had the same size (even if they varied in size from trial to trial), thresholds were low. When they had different sizes within a trial, thresholds were considerably elevated. This pattern of results is to be expected if the random variations in size induce a perceived variation in speed. Like some other stimulus variables (eg contrast and spatial frequency), size alters perceived

matching speed. However, random variations in it also affect discrimination thresholds which, it is claimed (McKee et al, 1986 *Vision Research* **26** 609–619; Chen et al, 1998 *Perception & Psychophysics* **60** 1329–1336), these other parameters do not.

◆ **The process of integrating directional information across speeds**

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We have found previously (Bill and Braddick, 1998 *Perception* **27** Supplement, 185) that subjects can integrate information from dots moving at two different speeds in judging the direction of global motion in a random-dot kinematogram. However, this integration appeared to depend on experimental designs which encouraged subjects to attend equally to both speeds. We examined whether integration across speeds depends on serially attending to the two speeds (1 and 8 deg s^{-1}), by varying stimulus duration (100–800 ms). Coherence thresholds for a direction judgment increase as duration is reduced. However, the increased thresholds for mixed displays where the signal consists of equal numbers of fast and slow dots are consistent with those for uniform 'fast' or 'slow' signals. Thus, the process of integration does not appear to depend on any serial switching of processing between speeds on a time-scale greater than 100 ms. We also investigated the range of speed differences for which integration of directional information occurs. Results suggest that this difference can be extended well beyond the 1–8 deg s^{-1} range previously tested. Although there is ample evidence for at least two speed-tuned mechanisms in human vision, it appears that information from them can be effectively combined for direction processing.

◆ **Linking component motions across space: only for specific forms**

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Linking component motions into a coherent global motion is thought to arise within the motion parietal pathway, known to be poorly sensitive to form information. Measuring direction discrimination with multi-aperture stimuli—outlined rigid geometrical shapes with hidden vertices—that requires motion linking across space and time, we found a strong influence of the spatial arrangement of visible segments on performance. Despite identical representations of component motions in velocity space, direction discrimination is close to ceiling for diamond-like closed shapes, but ranges from chance level (50%) to 75% correct for V-like or cross opened shapes. Regular repetitions of short sessions over 2–4 weeks indicate that perceptual learning occurs for diamond-like shapes but not for V-like and cross shapes (performance remains at about 75% correct). Adding feedback during learning does not yield significant improvement. In contrast, performance is high and roughly independent of shape type in eccentric vision or at low contrast in central vision. Together, our results indicate that virtual closure of disconnected segments is a powerful feature to link component motion across space. The origin of these effects, whether between form and motion pathways, or through early cortico-cortical connections is discussed.

◆ **Motion perception is not switched off during saccades**

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It is usually assumed that motion perception is actively suppressed during saccadic eye movements. However, we present a new phenomenon which indicates that motion perception is not switched off during saccades. Our basic stimulus was a leftward moving vertical grating (0.17 cycle deg^{-1}, 60 Hz) invisible under fixation. Subjects were required to do horizontal saccadic eye movements of various amplitudes. Eye movements were recorded (500 Hz) and saccadic peak velocities were computed off-line. Observers reported intrasaccadic perception with a keypress. With a leftward saccade, a vivid motion percept in the leftward direction appears when the peak velocity of the saccade is around 210 deg s^{-1} (amplitude about 6 deg). For smaller peak velocities (smaller amplitudes), the grating is perceived as moving with a lower apparent contrast. For higher peak velocities (larger amplitudes), the motion percept is gradually replaced by a 'flashed grating' percept. Moreover, the effect of motion adaptation on intrasaccadic contrast sensitivity suggests that the motion percept experienced during saccades is based on the activity of low-level direction-selective motion detectors. Saccades in the grating direction spread the temporal-frequency spectrum of the effective stimulus toward static channels. Motion perception is optimal when the spread includes motion channels but leaves out static ones.

◆ **Linear mechanisms and motion sharpening**

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Human observers are not normally conscious of blur from moving objects. Several recent reports have even shown that blurred images appear sharper when drifting than when stationary. Special nonlinear mechanisms have been proposed to explain this phenomenon. We present here an alternative explanation based on simple linear mechanisms and the negative or inhibitory part of the temporal impulse response of the visual system. First we show how the typical biphasic temporal impulse response can be accurately approximated by a difference of two Gaussian filters. Then we form a velocity-dependent spatiotemporal filter by combining this difference-of-Gaussians temporal filter with a difference-of-Gaussians or 'Mexican hat' type spatial filter. We apply the resulting filter to Gaussian-blurred edges and use the maximum gradient and the distance between the maximum and minimum in the output of the filter as measures of the amount of blur. Both measures show blurring in response to small blur widths and sharpening in response to larger blur widths. This is consistent with recent experimental findings, and shows that linear mechanisms can produce motion sharpening.

◆ **Local integration of features for the computation of pattern direction by neurons in macaque area MT**

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Component-direction-selective (CDS) cells in macaque MT respond to the movement of oriented features, while pattern-direction-selective (PDS) cells combine information about different orientations to compute the direction of movement of a coherent pattern. Because MT cells have large receptive fields (RF), we wondered whether PDS cells could combine directional information presented in separate parts of the RF. We recorded from MT neurons in anaesthetised, paralysed macaques, and characterised their directional selectivity for gratings and for plaids made by superimposing two gratings in a single region of optimal size and position. We then identified two responsive regions, each 25%–50% of the RF diameter, separated by 50%–75% of the RF diameter, and studied the direction selectivity of the cells with 'plaids' whose components were delivered separately, one to each region. The classification of cells as CDS or PDS depends on the relative accuracy of two models for plaid tuning data. When we separated the plaid components, the accuracy of the PDS model always decreased, while that of the CDS model stayed roughly the same. About half the cells were PDS for 'true' plaids, but only a few remained PDS when we separated the components. We conclude that the computations underlying PDS cells in MT are local, on a scale smaller than the whole RF.

MOTION INTEGRATION II

◆ **Combining components to predict perceived pattern motion**

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Spatiotemporal energy models that use first-order components as their only input cannot explain many results from experiments designed to investigate perceived pattern motion. Here a model is described which combines information from first-order components in a way that can explain many aspects of pattern motion. In it, Gabor filters that match orientation and spatial frequency of a pattern's components are convolved with the pattern in order to decompose the pattern into individual components. A directional derivative, with orientation perpendicular to the orientation of the Gabor filter is used to extract zero crossings for each component at time t_1. If two or more zero-crossings occupy the same position in two-dimensional space they are plotted as points in a two-dimensional plane. The method is repeated after a specified interval of time at t_2. The two-dimensional plane now has two sets of points representing the position of the points at t_1 and t_2. Motion direction is computed by a nearest matching method. This method essentially implements the intersection of constraints (IOC) but it can also predict results that are inconsistent with the IOC which are frequently interpreted as two-dimensional contrast feature tracking.

◆ **Coherent global motion from sequences of independent Glass patterns**
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We investigated the types of motion produced by sequences of Glass patterns of different construction and element type. Glass patterns were either rotational (pairs were made by rotating the position of an initial element positioned at random within a circle) or radial (pairs were made by radially shifting position). Element pairs ($N = 200$) were small circles, both white, both black (same polarity) or one white and one black (opposite polarity). Sequences of completely independent patterns of the same type (rotational or radial) were displayed at a rate of 16 Hz (SOA = 60 ms).

All Glass pattern sequences produced strong coherent motion, though none contained a coherent motion signal. Rotational patterns appeared to spin and radial patterns to expand or contract. Motion was also observed at the onset and offset of the display of a single Glass pattern. Since there is no coherent motion signal in a sequence of independent Glass patterns, the appearance of coherent global motion must derive from their static structure. We speculate that, when a collection of local motion signals has a vector sum near zero, the apparent direction of global motion may be set by static indications of structure.

◆ **Is segmentation of two motion-defined surfaces aided by differences in the spatial characteristics of the pattern elements?**
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Two sets of moving dots were combined to produce two motion-defined surfaces that were either transparent or adjacent. To provide an objective test of ability to segregate the two surfaces, observers were required to segregate the surfaces and then compare the direction of motion of one of them with a reference direction. In the control condition, all dots had the same luminance and contrast. In a second condition, dots belonging to the two surfaces had different luminances so as to make them perceptually distinguishable. In a third condition, the two sets of dots were drawn separately, bandpass filtered with different pass bands and then added. In a final condition, the dots were replaced by line elements and different orientations were used for the two surfaces. The results showed that differences in visual appearance do not facilitate the process of segregating the two moving surfaces, at least as measured in terms of precision of direction perception. None of the three manipulations affected performance in either the transparency or the spatial segregation case. It appears that the process of integrating local motion vectors over space to produce a global motion percept may be independent of the spatial characteristics of the stimuli.

MOTION MECHANISMS

◆ **A simple stimulus distinguishes Reichardt detectors from motion energy mechanisms**
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The outputs of Reichardt and energy models are very similar for most stimulus conditions. One potential method of distinguishing the models is to record from their subunits. With this approach, data recorded from cat visual cortex have been taken as evidence for the energy model (Emerson et al, 1992 *Vision Research* **32** 203–218). However, we note that those data are also predicted by the Reichardt model if the multiplicative nonlinearity is implemented by addition and squaring operations. We present a method for distinguishing between Reichardt and energy models by recording from the final detector output. The method relies upon the fact that the opponency stage in biological motion detectors is typically unbalanced, such that they respond not only to motion but also to temporal changes in luminance such as flicker or flashes. The response to luminance changes in the absence of motion is characteristic of the detector subunits. We recorded the responses of neurons in the optokinetic system of a marsupial mammal, the wallaby, to a briefly flashed grating stimulus. The data are consistent with the response properties of Reichardt detectors, but cannot be produced from an energy model regardless of the form of the filters employed.

◆ **Vision out of the corner of the eye**

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Sigmund Exner postulated that the extreme periphery of the retina contained primitive movement detectors, whose duty was to trigger foveation; and William James remarked on the discrepancy between movement thresholds in this region and our (much poorer) ability to resolve static stimuli. Yet there have been rather few modern comparisons of sensitivity to moving and stationary stimuli at large eccentricities. Using a forced-choice procedure, we have compared the detectability of moving and static gratings of varying spatial frequency in the extreme periphery. The measurements were made at the edge of the temporal field, at eccentricities ranging from 75 to 100 deg. The basic target stimulus was a vertical bar, subtending 1 deg × 9.3 deg. To minimise cues from scattered light, the bar was embedded in a larger rectangle of 11.9 deg × 9.5 deg of the same average luminance. During one of two temporal intervals on each trial, the bar was modulated sinusoidally along its length. In one experimental condition the modulation was static, and in the other the grating was moving (at 9.3 deg s^{-1}); in both cases the modulation was turned on and off according to a temporal Gaussian envelope. The peak contrast was 0.8. There were two main findings: (a) at extreme eccentricities, movement could be detected at spatial frequencies where the static modulation was invisible; and (b) in this part of the visual field, the contrast sensitivity function for both stationary and moving stimuli has a peak at a very low spatial frequency, of the order of 0.1 cycle deg^{-1} or less.

◆ **Isoluminant chromatic motion perception: defining the mechanism**

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The perception of motion in isoluminant chromatic displays has been asserted to be qualitatively different from that in luminance displays. We sought to determine the mechanism for isoluminant chromatic motion perception. (i) *Pedestal test.* The addition of a static red–green sine-wave grating (pedestal) to a moving red–green grating of the same spatial frequency abolished motion perception. This failure of the pedestal test suggests that chromatic motion perception relies on the tracking of features (ie peaks) and is computed in the third-order motion system. (ii) *Temporal tuning function.* The measured temporal tuning function (threshold modulation depth vs temporal frequency) exactly matched the previously measured tuning function of the third-order system. (iii) *Interocular motion.* Chromatic motion was perceived equally well when successive moving frames were presented monocularly or interocularly (so that no monocular motion information was available). Unlike first-order or second-order motion, but just like third-order motion, chromatic motion is as good interocularly as monocularly. *Conclusion.* The mechanism of isoluminant chromatic motion perception is third-order motion. It follows that isoluminant chromatic motion is not computed within the colour system, but at a brain level where binocular inputs of form, colour, depth, and texture are simultaneously available.

◆ **Temporal response to luminance and contrast modulation: second-order vision is as quick as first-order**

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The temporal properties of first-order and second-order visual detection mechanisms were derived from studies of temporal integration and two-pulse summation. Second-order stimuli were sinusoidal variations in the contrast of a dynamic white-noise carrier. First-order stimuli comprised similar sinusoidal variations of luminance either added to the noise carrier or presented alone. Data from the two-pulse summation experiment were used to derive temporal impulse response functions for the three types of modulation. These functions were then used to predict performance in the temporal-integration experiment. Impulse response functions were also transformed into the Fourier domain to give an estimate of the temporal (flicker) frequency characteristics for the three stimulus types. Detection of luminance signals without noise was characterised by a biphasic (transient) impulse response and bandpass frequency response. Luminance modulations in noise produced a monophasic (sustained) impulse response and low-pass frequency response. Contrast modulations of noise also produced a monophasic (sustained) impulse response and low-pass frequency response. The second-order impulse response was only slightly longer than that for luminance in noise, and the two stimulus types produced similar frequency characteristics. We conclude that second-order vision is at most only slightly slower than first-order vision in the presence of noise.

◆ **Computational modelling of interleaved first-order and second-order motion sequences and translating $3f+4f$ beat patterns**

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We examine two strands of evidence that are thought to show the existence of multiple mechanisms in human-motion perception. First, sequences of luminance-modulated and contrast-modulated patterns, which appear to move when presented singly, elicit no coherent motion percept when interleaved with a quarter cycle phase shift between modulants over successive frames (Ledgeway and Smith, 1994 *Vision Research* **34** 2727–2740). Second, for a $3f+4f$ beat pattern translating a quarter of a beat cycle each frame, forwards motion increasingly predominates over reversed motion as the inter-frame interval is increased (Hammett et al, 1993 *Vision Research* **33** 1119–1122). We apply a computational model of cortical motion processing (Johnston et al, 1999 *Proceedings of the Royal Society of London B* **266** 509–518) to the stimuli. When all frames within a sequence are luminance-modulated or contrast-modulated, the model detects the direction of modulant motion. In the interleaved sequences, the model detects no coherent motion. When the model is applied to a $3f+4f$ beat pattern with no inter-frame interval, reversed motion is indicated. Increasing the inter-frame interval leads to increases in forwards motion. Our findings demonstrate that some phenomena, thought to provide evidence for multiple motion mechanisms, may be accounted for by a single mechanism.

COLOUR, LIGHTNESS, AND BRIGHTNESS I

◆ **Kardos**

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While some theories of lightness are blind to the structure of the retinal image, Gestaltists have emphasised that object lightness is determined in relation to illumination frames of reference. But in fact lightness values are not computed exclusively within such frameworks. Kardos, another Gestaltist, saw more clearly how such frameworks interact: surfaces are seen both in relation to a 'relevant field' and in relation to a 'foreign field'. We announce an English translation of most of Kardos's book *Thing and Shadow*, and we report the replication and extension of several of his shadow experiments. In one experiment, a disk and annulus are suspended in mid-air, coplanar but separated by an annular gap of variable size, through which the observer sees a distant wall of a different illumination level. The weight of disk anchoring is shifted between the annulus and the far wall by either changing the gap size or moving the disk between the wall and the annulus. Coplanarity thus is graded, not the all-or-none effect proposed by Gilchrist (1980 *Perception & Psychophysics* **28** 527–538). Kardos observed that this explains failures of constancy but failed to note that it explains many lightness illusions as well.

◆ **Almost perfect colour constancy**

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Colour constancy assessed by colour matching with steady images is limited if the eye is not adapted to the illuminants. Yet performance in discriminating abrupt illuminant changes from surface-reflectance changes is fast and reliable (Foster et al, 1998 *Perception* **27** Supplement, 43). Can quantitative measures of colour constancy be improved? An experiment was performed in which observers binocularly viewed CRT computer simulations of an illuminated Mondrian pattern consisting of 49 (7×7) abutting, 1 deg $\times$ 1 deg square surfaces drawn randomly from the Munsell set. The pattern, subtending 7 deg $\times$ 7 deg when viewed at 100 cm, was illuminated for 1 s by a 25 000 K daylight and then for 1 s by a 6700 K daylight. In each trial, a randomly selected 1 deg $\times$ 1 deg square surface (and in the second condition a set of 24 such surfaces) in the second pattern was illuminated by an independent randomly selected illuminant whose CIE x, y coordinates were drawn from a 2-D array encompassing the first and second illuminants. Observers indicated whether the change was an illuminant change. The centroid of the CIE x, y illuminant coordinates for illuminant responses yielded Brunswick-like ratios quantifying the extent of the colour constancy. These ratios were close to unity. Human colour constancy may be better than previously estimated.

◆ **Statistical analyses of natural and man-made surface spectral reflectances**
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It has been postulated that the spectral reflectance functions of natural surfaces are highly constrained and that such spectra can be represented by linear models with a small number of (although more than three) components (Maloney, 1986 *Journal of the Optical Society of America A* 1673). This claim has strong implications for computational models of visual perception (eg colour constancy and transparency) and for the efficient representation of spectral digital images. It has also been claimed that natural metamers do not exist under incandescent light and natural daylight (Lennie and D'Zmura, 1988 *Critical Reviews in Neurobiology* 333). The aim of this study is to examine these claims by analysis of several new sets of reflectance spectra consisting of natural and man-made surfaces. The analysis techniques used were principal component analysis (PCA) and Fourier analysis. The components from PCA were used to construct basis functions; Fourier analysis was used (primarily) to determine the spectral-frequency-band limit of the reflectance sets. Further analyses considered the role of the illuminant in the constraints of colour signals. From this and other analyses we conclude that the construction of linear models to represent natural spectra requires more than twelve components, and that the abundance of natural metamers is extremely low.

◆ **A computational colour-vision model for colour appearance calculations**
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Colour appearance prediction remains a challenging area for theories of colour vision. Current models [Fairchild, 1998 *Color Appearance Models* (Reading, MA: Addison Wesley)] are parametric and considerably simplify the representation of the input image, typically reducing it to the equivalent of only a few uniform areas of colour. Appearance models will, in future, be used to process real-world imagery, in device-independent colour-imaging systems. We argue that the application of these simple models to complex imagery is inappropriate. To this end we are developing a synthetic observer for colour vision, designed to analyse complex imagery, whether real or rendered, in the same way as a human observer. No simplifying assumptions are made regarding the spatial structure in the imagery. The synthetic observer processes the imagery directly. The synthetic observer has already been used to model performance in simple psychophysical experiments. It can reproduce both detection and discrimination performance. It was found that the incorporation of retinal and cortical adaptation mechanisms was of critical importance to these predictions. We describe the components of the synthetic observer and illustrate the various predictions it produces for a variety of colour-vision experiments.
[This work was carried out as part of Technology Group 5 (Human Sciences & Synthetic Environments) of the MoD Corporate Research Programme.]

◆ **How powerful is the specularity cue in surface colour perception?**
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In a previous report (Yang et al, 1999 *Investigative Ophthalmology & Visual Science—ARVO Proceedings* in press), we have shown that among several cues to the illuminant, specularities had a marked effect on surface colour perception. Here, the specularity cue was further explored by changing four parameters of the rendered scenes: the size, number and colour of objects, the background colour, and the location of a test patch. Stereoscopic scenes were rendered with the physics-based rendering package RADIANCE, modified to render colour accurately, with the use of two illuminants, A and D65. Scenes were rendered under one illuminant, with specularities rendered as if under the other illuminant. Observers adjusted the test patch to appear achromatic. There was no effect of background colour, or object colour or size. With these changes, specular cues had the same influence as in our previous report: the influence was markedly greater when illuminant A was perturbed in the direction of illuminant D65. The same held true when the test patch was closer to the background in depth. However, as the number of objects decreased, the perturbation influence was eliminated. Together, these studies show that the visual system uses specularity cues to the illuminant in surface colour perception.

◆ **Integration regions of chromatic and luminance mechanisms in a hyperacuity task**
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Both chromatic and luminance mechanisms contribute to hyperacuity performance. At high luminance contrasts, a luminance mechanism determines threshold, and at low contrasts, with chromatic stimuli, chromatic mechanisms support detection (Rüttiger and Lee, 1998 *Perception* **27** Supplement, 177). A physiological basis is found in responses of M-ganglion and P-ganglion cells. However, threshold curves of human observers and cell neurometric thresholds show some differences. To find out how signals of ganglion cells are pooled in higher visual areas, we measured thresholds for detection of small displacements as a function of edge length and luminance contrast for achromatic and chromatic edges. For achromatic edges, higher contrasts are required for the edge to be visible at all with shorter edge lengths, and there is a change in slope of the contrast dependence for displacement detection. For chromatic edges, thresholds rise with shorter edges but the slope of threshold curves remains constant. Behaviour of the chromatic mechanism can be described by integration over stimulated retinal area, rather than along edge length. Luminance thresholds can be explained neither by a simple areal integration nor by edge-length integration. Luminance spatial information may be integrated in more complex ways, including nonlinear summation.

◆ **The components of chromatic and achromatic colours**
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Quantitative relations between perceived lightness, whiteness, and blackness of greys; and between lightness, whiteness, blackness, and chromaticness of the four unique hues were studied. In two experiments, observers evaluated on a 0–100 scale the lightness, whiteness, and blackness of 4 greys, and of 10 yellow and 10 red nuances. On the same scale, the same subjects also evaluated the greyness of the greys and the yellowness and redness of each yellow and red nuance, respectively. In agreement with previous findings (Masin, 1987 *Revista Latinoamericana de Psicologia* **19** 393–399), the results show that rated lightness of greys was a weighted average of rated whiteness and blackness. For yellow and red nuances, lightness also depended on hue. Some colour attribute seemed to increase the rating of some other colour attribute as the sum of the ratings of whiteness, blackness, and chromaticness almost always exceeded 100. In comparison with the corresponding NCS values, normalised chromaticness was systematically underestimated, and normalised whiteness and blackness overestimated. In the third experiment, different observers evaluated on a 0–100 scale the lightness, whiteness, and blackness of greys; and the lightness, whiteness, blackness, and chromaticness of blue and green.

◆ **Does grain size affect our perception of spectral content in coloured textures?**
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The appearance of materials can vary widely owing to variations in grain size. When seen from afar, foliage, for instance, appears to be almost uniformly coloured, yet a closer look often reveals a multitude of colours. In the present study, we investigated whether changes in texture grain size influence the perception of spectral content. We asked observers to adjust the spectral content of coloured textures until it matched that of textures with a different grain size. We presented a square split stimulus (12 deg). The top half always contained coloured squares of 7.5 min arc, the bottom half contained coloured squares of 15, 10, 7.5 or 3.75 min arc side lengths. The colour of each square was randomly chosen from a linear distribution around medium grey. This distribution was oriented in one of three directions: the light–dark, the red–green, or the blue–yellow direction. Observers were asked to match the range of colours present in the bottom half of the stimulus to the range of colours present in the top half of the stimulus. Observers surprisingly good at matching spectral content. We found only a marginal influence of grain size on the perception of spectral content in the stimulus.

◆ **Detecting the presence of a 'non-normal' illumination: Cues based on second-order statistics of colour codes**
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Physical analyses and phenomenological observations suggest that the 'spatial variance of colour codes' of the incoming light array is a reliable regularity on which an inference can be based as

to whether a chromatic deviation of the space-averaged colour codes from the neutral point is due to a 'non-normal', ie chromatic, illumination or to an imbalanced spectral reflectance composition. We provide evidence that the visual system uses second-order statistics of chromatic codes of a single view of a scene in order to disambiguate 'illumination' and 'object' properties and to segregate local retinal signal into a dual code for 'object colour' and 'illumination colour' (understood as perceptual categories). We used centre–surround configurations with nonhomogeneous surrounds—referred to as Seurat configurations—where the surrounds are given by a random structure of overlapping circles of fixed diameter. Each family of surrounds has a fixed space-average of colour codes, but differs in the covariance matrix that defines the chromatic variance along some chromatic axis and the covariance between luminance and chromatic channels. The dominant wavelengths of red–green equilibrium settings of the infield exhibited a stable and strong dependence on the chromatic variance of the surround.

COLOUR, LIGHTNESS, AND BRIGHTNESS II

◆ **Time course of adaptation for colour appearance and discrimination**

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Adaptation to a steady background has a profound effect on both colour appearance and discriminability. We determined the temporal characteristics of adaptation for appearance and discrimination, and for changes along different colour directions. Subjects were adapted to a large uniform background made up of a CRT screen and a 60 deg × 60 deg wall illuminated by computer-controlled lamps. After an instant change in background colour along the red–green or blue–yellow cardinal colour axes, we measured thresholds for the detection of increments or decrements along the same axes at fixed times between 16 and 120 s. Analogously, colour appearance was determined by means of observer production of achromatic appearance. We found a slow exponential time-course of adaptation with a half-life of 20–30 s that was common to appearance and discrimination. Also, a 50–100 ms component could be identified, which was probably due to photoreceptor adaptation. There was an extremely fast mechanism with a half-life faster than 10 ms, but only for colour appearance. There were no differences for adaptational changes along the different colour axes. We conclude that the fast adaptation mechanism for colour appearance is of higher order and is situated after the mechanisms mediating slower adaptational changes in colour discrimination and appearance.

◆ **High-spatial-frequency tritanopia**

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There are a variety of colour appearance phenomena arising from poor spatial resolution of the short-wavelength (S) cones, particularly small-field tritanopia and tritanopia of the central foveola. We present another visual phenomenon which also seems to reflect the lack of spatial resolution for the S-cones. A few lines of small grey areas surrounded by a yellow–green colour seem to be tinged with yellow whereas the same array surrounded by pink appears to be tinged with blue. The saturation of the illusory colours was found to be largely dependent on the angular separation of the lines, rather than on the angular size of the whole array, thus distinguishing this phenomenon from small-field tritanopia. On the other hand, contrary to foveal tritanopia, which requires a gaze fixation, the illusory coloration of the areas does not depend on the gaze direction. We report some quantitative data obtained on the effect of the angular separation on the illusory colours which were measured by using an asymmetric colour-matching technique. Specifically, the S-cone contrast of the match was recorded as a function of the spatial frequency (a reciprocal of the angular separation between the lines). The results are compared with the S-cone contrast sensitivity as measured by other researchers.

◆ **Colour naming and cognition: two tests of the Sapir–Whorf hypothesis**

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We compared Bantu-speakers, without basic terms for orange, purple, or pink, with English-speakers, to see whether there were associated cognitive differences. Subjects chose which colour was the odd one out among three when they could see one, two, or three stimuli at a time. Colours crossed category-name boundaries for English but not for Bantu. English-speakers were more likely than Bantu-speakers to make choices consistent with the English categorical structure and the difference increased inversely with the number of colours seen at once. In the second task, subjects searched for target colours among 168 colours using a matching-to-sample procedure. There were either one or two targets, and colours either fell in the same English category

(eg orange) or adjacent categories (eg orange and red); these were included in the same African language category. For English-speakers, there either were or were not non-targets in the same category as the target(s). There were strong effects of number of targets and type of non-target, but no effect of language. Overall, the two language groups behaved very similarly, but even so there were differences consistent with the Sapir–Whorf hypothesis, particularly as memory demands increased.

◆ **Discriminability of brightness as function of intermediate probe distance**
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On the basis of the distinction of two processing stages, namely the forming of boundaries and the filling-in of colour, we investigated the precision with which the brightness of two rectangular fields can be discriminated as a function of intermediate distance. The general idea is that two adjacent fields that are almost equal in luminance cannot form clear-cut boundaries. As a result, the colours can spread over the two fields like wet paint in the filling-in stage, resulting in poorer accuracy of discrimination. At some distance (depending on the sizes of the receptive fields involved in boundary detection), clear boundaries are formed, and the accuracy of discrimination should be better. The frequency of seeing one specific field brighter than the other as a function of luminance difference was measured by the MUEST method (Snoeren and Puts, 1997 *Journal of Mathematical Psychology* **41** 431–439). The steepness of this psychometric function, which is directly estimated by MUEST, was used as a measure of the above-mentioned accuracy. In accordance with the prediction we found a maximum accuracy at an intermediate distance of about 2 min of arc. Thereafter, the accuracy steeply descended to equilibrium for even larger distances.

◆ **Lightness from early-vision spatial comparisons, mid-vision junctions, or high-vision perceptions: the debate—Part 1**
A D Logvinenko, J McCann¶ (School of Psychology, Queen's University of Belfast, Malone Road, DKB, Belfast BT9 5BP, Northern Ireland, UK; ¶ McCann Imaging, 161 Claflin Street, Belmont, MA 02478, USA; fax: +44 1232 664 144; e-mail: a.logvinenko@qub.ac.uk)
The pair of talks integrates two independent sets of Adelson-like experiments on lightness. Part 1 introduces luminance gradients in Adelson's patterns. It presents new demonstrations which challenge early-vision and Adelson's mid-vision models of lightness, as well as Gilchrist's anchoring theory. In one demonstration there is a strong lightness induction (LI) even though no apparent transparency is observed. In the other there is a clear impression of transparent strips, yet no LI is present. Separating the tiles in the Adelson pattern does not affect the impression of transparency, and does not affect the grey-level junctions. Nevertheless, it makes the LI effect vanish. In Part 1 we argue that LI is too complex to be accounted for by a single model. Apart from the effects of rather weak early-vision mechanisms (found in textbooks), there must be another mechanism which is responsible for much stronger magnitudes of LI effect, particularly those from using luminance gradients. Part 1 suggests that LI of the second type is a phenomenon of pictorial (as contrasted to natural) vision, which incorporates lightness–shadow invariance in a similar way as Gregory's 'inappropriate constancy scaling' theory of geometrical illusions incorporates size–distance invariance.

◆ **Lightness from early-vision spatial comparisons, mid-vision junctions, or high-vision perceptions: the debate—Part 2**
J McCann, A D Logvinenko¶ (McCann Imaging, 161 Claflin Street, Belmont, MA 02478, USA; ¶ School of Psychology, Queen's University of Belfast, Malone Road, DKB, Belfast BT9 5BP, UK; fax: +1 617 484 2490; e-mail: mccanns@tiac.net)
This pair of talks integrates two extensive sets of Adelson-like experiments on lightness. In Part 2 it is argued that modification of the diamonds experiments demonstrate an early-vision explanation, without reliance on illumination, transparency, apparent depth, and junctions. Grays ordinarily look darker on light backgrounds. Adelson showed that two rows of diamonds looked the same on different backgrounds when the diamond tips crossed into the other background. Adelson added different grey tips, consistent with illumination changes, thus releasing the rest of the diamonds to no longer match. Grays on light backgrounds reverted to looking darker. New experiments show that the introduction of any edge along the light–dark background boundary releases the diamonds to look different in different surrounds. Whereas Adelson introduced diamond tips consistent with illumination, we used lines, dots, Craik–Cornsweet edges, non-consistent tips and no tips to release the diamonds to look different. Adelson's tips and all of our edges produce

essentially the same magnitude of lightness shifts. All are equal to greys on lighter and darker backgrounds. The same results are found for small abstract displays (one-quarter diamond). These experiments are arguments for early-vision lightness mechanisms.

◆ **Illumination intensity and field size determine pattern of lightness errors**
S Zdravković, A Gilchrist (Department of Psychology, Rutgers University, 101 Warren Street, Newark, NJ 07102, USA; fax: +1 973 353 1171; e-mail: suncica@psychology.rutgers.edu)

Lightness constancy is not perfect and the pattern of errors must be the signature of visual processing. We projected either a rectangular spotlight or a rectangular shadow horizontally across the middle of a row of adjacent vertical rectangles of differing (black to white) reflectance. Using a Munsell chart, observers matched (a) the part of each rectangle in higher illumination, (b) the part in lower illumination, and (c) the whole rectangle. We obtained a pattern of errors with three main components: (i) a graded series of errors, with light greys failing more in low illumination, dark greys failing more in high illumination, as predicted by anchoring theory; (ii) greater errors occurred in the region of smaller field size, consistent with Katz's law of field size; and (iii) matches to the whole region agreed with matches made in the illumination field of larger area.

◆ **Further evidence for an anchoring account of simultaneous lightness contrast**
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According to anchoring theory (Gilchrist et al, forthcoming *Psychological Review*) simultaneous lightness contrast (SLC) is the product of perceptual organisation. Previously we showed that the main error is expressed by the target on the black background, consistent with anchoring theory, but not lateral inhibition [Annan et al, 1998 *Investigative Ophthalmology & Visual Science* **39**(4) S158]. Galmonte and Agostini [1998 *Investigative Ophthalmology & Visual Science* **39**(4) S158] recently presented a variation of SLC in which the illusion is opposite to that predicted by lateral inhibition. Using our own version of this effect (reverse contrast) we showed how the strength and the direction of SLC depend on the strength of grouping factors [Economou et al, 1998 *Investigative Ophthalmology & Visual Science* **39**(4) S857]. We now report two experiments in which target and background luminances are varied. Matches made with a standard 16-step Munsell chart show that (i) the strength of illusion increases as target luminance is lowered and (ii) the strength of illusion varies with a change of background luminance only when background luminance exceeds target luminance. Both of these results are consistent with the anchoring model but not with lateral-inhibition models.
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Wednesday

SYMPOSIUM

SEEN VS UNSEEN: NEW ISSUES IN THE PSYCHOPHYSICS OF DECISION

◆ **Seen vs unseen: new issues in the psychophysics of decision—Introduction**
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The frontier between 'seen' and 'unseen' is problematic in two intertwined ways: it is referred to in the context of dormant or possibly unsound definitions of what 'seen' actually means and, as a consequence, it is investigated with potentially inappropriate experimental tools. These two issues are discussed within the framework of signal detection theory and classical psychophysical techniques and with reference to changes in the response criterion and in the signal-to-noise ratio induced by factors such as a priori response biases, masking, contextual effects, attention, and delayed responses. I suggest that a number of 'mysterious' experimental (eg 'subliminal' priming, change blindness, inattentional blindness) and neuropsychological phenomena (eg blindsight, hemineglect) could be accounted for, at least partly, in these terms. The seen/unseen frontier is tentatively reformulated with reference to the concept of awareness for which I dare offer a restrictive but formal definition. I conclude by pleading (together with William James) that a number of the frequent pitfalls associated with the discussion of the issues above could be avoided by means of a more incisive use of our introspection.

◆ **How invisible properties of a prime determine the visible ones of a mask**
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We present a powerful new illusion in which a briefly displayed line Vernier bequeaths its offset to a test grating comprising five nonaligned Verniers. If the presentation time of the priming Vernier is short (10 – 100 ms) the prime itself does not reach the conscious level. However, the test grating presented afterwards is perceived as offset (though it is not). Surprisingly, the Vernier can be rendered visible when more bars are added to both sides of the grating. This change of percepts also yields an increase of visual sensitivity; that is, the discrimination threshold for the direction of offset of the visible Vernier when 25 non-offset Verniers are used in the test grating is half the threshold for the invisible Vernier when the mask is composed of only 5 nonaligned Verniers. We conclude that masking, temporal integration, and conscious perception cannot be explained by models focusing only on local features of the stimulus, because contextual elements are crucial for behavioural performance as well as for subjective experience.
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◆ **Unconscious priming of object change**
D Fernandez-Duque, I M Thornton¶ (Department of Psychology, University of Oregon, Onyx Street, Eugene, OR 97403-1227, USA; ¶ Cambridge Basic Research, Nissan Research and Development Inc., 4 Cambridge Center, Cambridge, MA 02142, USA; fax: +1 541 346 4911; e-mail: duque@uoneuro.uoregon.edu)

Although observers are often poor at reporting changes to their visual environment, recent evidence suggests that observers can correctly 'guess' the location of change even when they report being unaware that any change had occurred (Fernandez-Duque and Thornton, in press *Visual Cognition*). To further explore this implicit representation of change, we combined a simplified change blindness paradigm with a priming paradigm. A ring of 8 rectangles (half horizontal, half vertical) was shown for 250 ms. During an intervening blank period (250 ms), one rectangle changed orientation, and the whole array then reappeared for 250 ms. Immediately following the rectangle display, one rectangle was highlighted either at the location of change or at a diametrically opposite location. Observers made a speeded vertical/horizontal discrimination to the highlighted rectangle, after which they indicated whether they 'saw' any change in the initial display. Errors in the orientation task were most frequent for unaware trials in which the orientation of the highlighted rectangle conflicted with the final orientation of the changed item. These results suggest that the visual system can implicitly represent change.

◆ **Divided attention and neglect: an electrophysiological and psychophysical study**
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Studies on patients with neglect showed longer visual evoked potential (VEP) latencies to stimuli displayed in the neglected hemifield (LVF). However, in a large sample study (Angelelli et al,

1996 *Neuropsychologia* **34** 1151 – 1157) a few patients did not conform to the general trend. Three of these patients were studied in depth, testing the hypothesis that the attentional load of the task might modulate VEP latency. VEPs were recorded in the baseline condition (simple fixation) and in an attentional load condition (discrimination of brief and long light onset). Longer VEP latency to LVF stimuli was found when attentional resources were challenged. Similarly, at the behavioural level, the divided attentional paradigm caused a decrement in the percentage of correct responses in a detection task. On the other hand, the attentional manipulation did not produce effects on VEPs of patients who had no attentional deficit. Longer VEP latencies to contralesional stimuli are a good marker of unilateral attentional deficit.

◆ **Prolonged inattentional blindness for a visually distinctive, dynamic object**
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Observers sometimes fail to see unanticipated, suprathreshold stimuli when attention is focused on another task [Mack and Rock, 1998 *Inattentional Blindness* (Cambridge, MA: MIT Press); Simons and Chabris, 1999, Poster presented at the 3rd Annual Vision Research Conference, Fort Lauderdale, FL]. We examined the extent of 'inattentional blindness' for a visually distinctive object in a dynamic display. While maintaining fixation, observers viewed four white and four black shapes, each moving on a continuous, random path. On each trial, they counted the number of times the white (or the black) shapes contacted the edges of the display window. On the third (critical) trial, an additional object unexpectedly entered from the right and traveled linearly across the screen, passing through the fixation point and exiting on the left. Detection of the unexpected object was influenced by the similarity of the target object to the attended and ignored items. Yet even when the unexpected object was the only coloured object in the display (a red '+') nearly 30% of observers reported not seeing it. Almost all observers noticed the unexpected object on the final trial when they were not required to perform the counting task. Thus, even when the unexpected object differed in colour, shape, and motion from all other items in the display, many observers exhibited a prolonged (5 s) inattentional blindness.

◆ **Maximisation of information in binocular rivalry**
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We studied the dynamical construction of visual awareness where inputs from the two eyes do not necessarily fuse into a single image, including the binocular-rivalry condition. We found that the spatiotemporal structure of what the subject observes in visual awareness is strongly affected by the spatial pattern of correlation of features in the two rivaling inputs. Under certain conditions, we found that we were able to control the spatial distribution of the resulting ocular dominant areas in the visual field by using partially low-pass filtered image. One surprising finding is that ocular dominance can occur in a patchy fashion, even violating continuity and connectedness in the topological sense. Thus, the visual system seems to be able to 'design' the ocular dominance pattern in the visual field in quite a flexible manner. Our analysis shows that the general criterion for the resulting ocular dominance pattern is to maximise the available information, in which the image giving the more information of the two rivaling images for a particular locus in the visual field is 'chosen' to emerge in visual awareness. We put forward a general mathematical model which explains these properties of binocular rivalry.

◆ **The bare bones of object recognition: Implications from a case of object recognition impairment**
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Three experiments were designed to investigate the performance of a patient (RK) who could name objects when presented in conventional views but showed catastrophic failures in identification of unconventional views. The aim of all three experiments was to assess the properties of the central representations that allow recognition of objects presented in conventional but not unconventional views. All three experiments showed that RK had problems in object identification not apparent from his naming performance. In the first experiment, RK was found to be extremely impaired at recognising the parts of objects even though he could name the whole object. In the second experiment, alterations in colour, shape, and parts of objects were undetected in stimuli he could name. In the third experiment, RK showed considerable difficulty with mirror images and inversion tasks. The explanation for RK's impaired object recognition could not be attributed to

defects in his early visual processing. We argue that RK's recognition is achieved through abstract (object-centred) representations that are global rather than local, and quite independent of their spatial framework. These abstract representations we take to be essential bare bones for object recognition.

◆ **Do normal observers hallucinate contrast signals?**
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Standard signal detection theory (SDT) assumes that contrast signals are detected in the presence of noise. In a 2AFC task, for example, there is assumed to be noise masquerading as signal in both the target and the distractor intervals, and the ideal observer selects the interval containing the larger signal as the one containing the target. It follows that threshold should rise with the number of distractor intervals, since each interval contributes independent noise to the task. We find, however, that detection performance in an 8AFC contrast-detection task is very similar to that in a 2AFC task. As soon as external noise is added to the intervals, 8AFC performance deteriorates relative to 2AFC in the manner predicted by SDT. We infer that internal noise is negligible in this task, and that errors in 2AFC are guesses rather than hallucinations. The results differ from those for orientation encoding (Morgan et al, 1998 *Quarterly Journal of Experimental Psychology* **51** 347–371) where thresholds do increase with the number of distractors, as predicted by SDT. We infer that orientation coding, but not contrast detection, is noisy. The difference may depend upon the nonlinear transduction process for contrast. In a further attempt to measure hallucinations, we gave observers a 2AFC task in which they had a third button to indicate when they saw signals in both intervals. Signals were actually present in both intervals on half the trials. Practised observers hardly ever pressed the 'both' button on single-interval trials, and 2AFC performance was not affected by the insertion of 'both' trials. We conclude that contrast hallucinations are rare events. The implication of these findings for the 'blindsight' literature are discussed.

◆ **Transcranial magnetic stimulation of occipital cortex in a subject with blindsight and a subject with ocular blindness**
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Subjects with blindsight caused by damage to visual area V1 occasionally have conscious percepts elicited by contrasty swiftly moving stimuli. To determine whether this reflects residual visual processing in extrastriate visual area V5/MT we tested a blindsighted subject with repetitive transcranial magnetic stimulation (rTMS) over V5/MT. On the normal side, swirling visual phosphenes, localisable with respect to his fixation point, were elicited by rTMS applied over the position of V5/MT, but never by stimulating region V5/MT in the damaged hemisphere. In contrast, swirling phosphenes were elicited in a peripherally blinded subject by stimulating V5/MT. They were achromatic and appeared to the subject to be within 20 deg of an imagined fixation point. rTMS was also applied in the totally blind subject over the occipital midline. Stationary coloured phosphenes were readily elicited in the lower visual field. We conclude that even years after the eyes have been severed from the brain, striate cortex and area V5/MT remain excitable and can generate visual percepts. But in the absence of V1, stimulation of ipsilateral V5 no longer yields conscious visual percepts, at least with the stimulation conditions we used.

◆ **Decision criteria are regulated by a unique 'anchor' in a multistimulus environment**
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The question whether observers can entertain multiple response criteria in a multistimulus environment was addressed by means of a modified partial-report paradigm whereby d' and criterion c were assessed in 3 subjects for one out of one ('single'-condition), or out of two ('dual'-conditions), 3 cycles deg^{-1} Gabor targets of contrasts C_1, C_2 ('dual–same': $C_1 = C_2$; 'dual–different': $C_1 \neq C_2$. In 'single–same' and 'dual–same'-conditions, zFA-values follow, as expected, the signal probability manipulations. In the 'dual–different'-condition, zFA-values are biased in such a way that their difference along the sensory scale is always reduced by $(d'_2 - d'_1)/2$.

This finding (replicated with a variety of C_1, C_2 pairs yielding differences between 0.7 and 2) is accounted for by posing that subjects set their criteria relative to their current estimates of the internal responses and that they cannot entertain two (or more) such estimates simultaneously even when the different-strength signals are unambiguously identifiable. Instead, subjects appear to mix the corresponding internal response distributions, thereby using a unique internal 'anchor' for setting their criteria—or awareness levels—as a function of signal probability.

ORAL PRESENTATIONS

ILLUSORY CONTOURS, AMODAL COMPLETION, AND OCCLUSION

◆ **Contour synthesis in moving displays**

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When outline figures were translated behind an invisible straight vertical occluder, vivid illusory occluding contours formed, which appeared to deform nonrigidly in a manner opposite to that predicted by models of illusory-contour synthesis. These contours were extremely robust, and could not be eliminated by either subjective contours that specified a straight occluding edge, or by visible contrast on the occluding surface. It is shown that the deformation in the shape of an illusory contour cannot be explained by models of illusory contour formation that rely on the geometric properties of the stimuli. If the velocity of the contour terminators of a partially occluded figure remains constant, the illusory contours will simply be scaled copies of each other. However, if the contour terminators have a variable velocity, then the illusory contours do not possess this scaling property. The shape of the illusory contours can be understood with a model that computes the angle formed by an induced translation velocity of the illusory occluding surface, and the velocity of the contour discontinuities generated at the points of occlusion.

◆ **Some investigations at the edge of amodal completion**

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Research on amodal completion typically involves rather stylistic geometric 2-D shapes. Two extensions of the stimulus domain are considered here. The first extension concerns completions of 3-D objects. More specifically, completions of the back of an object are examined (van Lier and Wagemans, 1999 *Journal of Experimental Psychology: Human Perception and Performance* in press). The second extension concerns so-called fuzzy completion (van Lier, 1999 *Acta Psychologica* in press). These completions involve global extrapolations of quasi-irregular partly occluded shapes. It is argued that in both cases the preferred percept cannot be explained on the basis of local configurations. Instead, global aspects appear to play a crucial, if not decisive, role. Explorations on 3-D-object completion and fuzzy completion potentially cumulate in further research on 'fuzzy object completion', involving a wide and rich variety of stimuli. It is argued that completions should ultimately be regarded as an inextricable part of object interpretations. Finally, the proposed extension further feeds the intriguing 'Kanizsa question' on the origin of amodal completion: seeing or thinking?

◆ **Temporal limits in attentional tracking of an invisible moving object**

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To examine the time course of mental tracking, we made subjects view a dot moving along a circular path about a central fixation point. After 90° arc length of visible motion at constant speed, the dot disappeared for 500–5000 ms (occluded period) and then reappeared either at the location appropriate for the initial speed, or angularly displaced 15°–180° arc length ahead of or behind the appropriate location (angular offset). Subjects were instructed to maintain fixation and mentally track the movement of the dot after it disappeared. In experiment 1, the time to react to the dot's reappearance was measured as a function of angular offset. Reaction times were fastest for appropriate reappearance, and increased systematically with larger angular offsets, but only for occluded periods $<\sim$3000 ms. In experiment 2, subjects were asked to judge whether the dot reappeared ahead of or behind the appropriate location, using a 2AFC paradigm. The slope of the psychometric function (% ahead/behind judgment vs angular offset) was steep for short occluded periods, but steadily decreased with longer occluded periods, so that by 3000 ms subjects performed no better than chance. These data suggest that attentional tracking of an invisible moving stimulus decays markedly within $\sim$3000 ms.

◆ **The role of flicker and motion in the perception of illusory contours**
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Pradzny (1985 *Perception & Psychophysics* **37** 237–242) reported that static or purely translating inducers defined by motion discontinuities or flicker do not result in the perception of illusory contours. This failure has been attributed to the fact that each translating inducer defines a single part of the 'illusory' figure over time. In contrast, cues consistent with dynamic occlusion, such as accretion/deletion and/or sequential exposure of different parts of the illusory figure, result in the perception of salient illusory contours in such configurations [Pradzny, 1986 *Perception & Psychophysics* **39** 175–178; Kellman and Loukides, 1987, in *The Perception of Illusory Contours* Eds S Petry, G E Meyer (New York: Springer)]. In our study we used inducers defined solely by discontinuities in temporal modulation with the absence of accretion/deletion or sequential exposure cues. 'Thin'/'fat' shape discrimination thresholds for briefly presented configurations (150 ms) were measured in a forced-choice procedure (Ringach and Shapley, 1996 *Vision Research* **36** 3037–3050). The results show that, for static backgrounds, static discontinuities in flicker are sufficient to induce perception of illusory contours. Figure/ground reversals of static and time-modulating regions resulted in a profound increase in shape discrimination thresholds. Differences in the direction or speed of motion within the inducers showed no effect.

CONTRAST

◆ **Flanker effects on contrast discrimination**
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Flanking Gabors facilitate the detection of a Gabor target of identical orientation and spatial frequency (Polat and Sagi, 1993 *Vision Research* **33** 993–999). Here we report how flankers affect the discrimination of Gabor contrast. We used a spatial 2AFC design in which two Gabor targets appeared simultaneously to the left and right of fixation (4 deg eccentricity). Observers reported which contrast was higher ('left' or 'right'), and discrimination thresholds were established as a function of pedestal contrast. Aligned Gabor flankers were placed at a fixed distance (3 times Gabor period) on both sides of each target. Flanker contrast remained constant during each session, and was either 70%, 40%, 20%, or 0% (no flankers). Without flankers, thresholds follow the well-known dipper function, whereas with flankers they reveal a complex 'W-shaped' dependence on pedestal contrast (thresholds decrease, increase, decrease again, and increase again). The pedestal contrast for which the 'W-function' reaches its central peak increases with the flanker contrast. It appears that flankers flatten the contrast response function for intermediate contrasts, creating a double-sigmoid function with two steep regions on either side of a flat region. The two steep regions explain the two local minima in the 'W-function'.

◆ **The role of target contrast in the Pulfrich stereophenomenon**
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In the usual explanation of the Pulfrich illusion, the dark filter over one eye is thought to slightly dark-adapt that eye causing it to respond with an increased latency. For any moving target, the increased latency creates a binocular disparity which is seen as a displacement in depth. To distinguish between the effects of adaptation, space-average luminance, and target contrast, the background luminance was kept the same in both eyes and only the luminance of the moving target was varied. Observers fixated a stationary point while viewing the oscillating line target and judged the apparent direction of rotation in depth of the moving target. The luminance of the background to one eye was then adjusted to null out any perceived rotation. When the display consisted of targets lighter than the background, there was a Pulfrich effect consistent in direction with the lighter target creating a shorter latency. However, when the display consisted of darker targets, there was a small but significant Pulfrich effect such that the eye viewing the darker target created the shorter latency. This result suggests that target contrast affects visual latencies independently of space-average luminance or adaptation level.

◆ **Orientation discrimination is improved both by collinear and noncollinear flanking stimuli**
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At last year's ECVP we reported (Morgan and Solomon, 1998 *Perception* **27** Supplement, 54) that contrast detection thresholds for a small Gabor patch of grating were reduced by the presence of collinear flanking stimuli. This 'long-range facilitation' effect was lost, however, if the target was

completely surrounded by an annulus of flanking patches. We now report that orientation discrimination thresholds of $\sim 5°$ for the tilt of a small Gabor patch are lowered to $\sim 0.5°$ by the presence of collinear patches which have the same tilt as the target. In other words, there is spatial summation of orientation information across collinear patches. The facilitation effect is greater if the phase of the grating is the same in the target and flanking patches. However, facilitation is also produced by noncollinear flanking stimuli, and in this case the facilitation is independent of relative phase. The results support the idea that orientation signals can be averaged across spatially distinct patches (Morgan et al, 1988 *Quarterly Journal of Experimental Psychology* **51** 347–371; Baldassi and Burr, 1999 *Investigative Ophthalmology & Visual Science* **40** S973), but there is also evidence for a further nonlinear combination mechanism.

◆ **No evidence for lateral contrast gain control among non-Fourier, contrast-modulated components**
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We previously reported that contrast–contrast phenomena show orientation tuning and phase specificity when simple luminance-modulated (LM) gratings are used, but show no specificity with plaid patterns. These results indicate two sources of gain control, at primary and higher levels of processing. We now investigate lateral contrast interactions with non-Fourier, contrast modulated (CM) patterns. Stimuli were centre–surround patterns comprising CM/CM or CM/LM combinations. CM gratings were generated by horizontally modulating the contrast of a carrier grating (6 cycles deg^{-1} at 45°) at 1.5 cycles deg^{-1}. The centre was always a CM grating (49% modulation depth). The surround contained LM-only or CM gratings at same or orthogonal orientations. Apparent modulation of the CM component was measured and compared to the physical depth of modulation. Results indicated small amounts of suppression when centre and surround contained similar CM gratings, but only when centre and surround carriers were identically oriented. A similar amount of suppression occurred with carriers alone in the surround. Little or no suppression was found when LM gratings were orthogonal in centre and surround (regardless of CM modulation) or matched CM modulation in SF and orientation. We conclude that no higher-level source of gain control is revealed with our non-Fourier, CM stimuli.

EYE MOVEMENTS

◆ **The time-course of saccadic suppression**
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We examined the time-course of saccadic suppression and tested whether it results entirely from retinal image motion or has an extraretinal component. We measured contrast thresholds for low-frequency gratings modulated either in luminance or colour, at 17 cd m^{-2} and 0.17 cd m^{-2}. Gratings were flashed before, during, or after either a voluntary 12-deg saccade or a saccade simulated by mirror motion. Suppression was found only for luminance-modulated gratings. Suppression starts 50 ms before, and is maximal at, saccadic onset where thresholds are increased tenfold. At lower luminance, the maximum becomes broader and weaker. Simulated saccades produce shallower suppression over a longer time-course at both luminances. Adding high-contrast noise to the display increased the magnitude and the duration of the suppression during simulated saccades but had little effect on suppression produced by real saccades. Saccadic suppression, specific to luminance-modulated stimuli, starts well before saccades. Differences between real and simulated saccades in the magnitude and time-course of sensitivity loss suggest that saccadic suppression has an extraretinal component. Saccadic suppression anticipates image motion and may provide immunity to its effects including conscious awareness of it during saccades.

◆ **Blinking or blanking: What helps against saccadic suppression of displacement?**
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When visual stimuli are displaced during saccadic eye movements, the displacement is often not noticed. This saccadic suppression of image displacement (SSID) can be eliminated by blanking the stimulus for a short period during and after the saccade (Deubel et al, 1996 *Vision Research* **36** 985–996). Here we studied SSID when the target's visibility was interrupted by a voluntary blink instead of a distal target blanking. Subjects combined their saccades to a visual target in

darkness with voluntary blinks. Eye movements were recorded with the search-coil technique. Our first experiment demonstrated that an analysis of the blink artifact in the eye-movement traces made it possible to estimate when visual information becomes available at the end of each blink. In the second experiment, the target was blanked with saccade onset and reappeared after a variable delay, at a slightly displaced position. The subjects had to indicate the direction of displacement. The results show that without blinks SSID disappears with blanking the target, confirming our former findings. When visual reafference is absent owing to a blink, however, SSID remains high. So, the effect of blinks on SSID is different from that of distal target blanking, evidence for an extraretinal signal that distinguishes between endogeneous and exogeneous sources of temporary object disappearance. In conclusion, blanking helps, blinking doesn't.

◆ **Strategic control of eye movements in multi-target visual search**
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Recent research questioned the role of memory and strategy in visual search [Horowitz and Wolfe, 1998 *Nature (London)* **393** 575–577]. We analysed the ocular search strategies of normal subjects during search for multiple targets embedded in a distractor field. Ten normal young observers searched for 19 targets (L-shapes), randomly embedded amongst 44 nontargets (distractors, + or T-shapes). While fixating each target, observers pressed a response button. They were asked to ensure that they found all the targets but not to deliberately reclick on a target that they had previously located. A spatial strategy was apparent in the sequence of eye movements generated by each observer, the efficiency and repeatability of which were quantified by using Markov matrices. Although subjects used an ordered search strategy, on average 20% of targets and 4.5% of previously fixated distractors were refixated. However, subjects only reclicked on 4.5% of targets, indicating that they had efficiently recalled the locations of previously found targets. There was no difference in the refixation or reclick rates for the two types of targets. The results suggest a role of spatial working memory and attentional inhibition of return in visual search in normals and neurologically impaired patients.

◆ **Topological structure allows for fast search with eye movements**
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We conducted visual search studies recording eye movements to examine whether subjects could locate a target amongst seven distractors accurately. Our primary interest was to see if a topological distinction between target and distractors would be sufficiently salient to guide the first saccade to a target. Stimuli were positioned in an around-the-clock array and all items were equidistant from the centre of the display. Four experiments were conducted. In the first experiment, subjects had to locate a square with a dot just outside its perimeter within a set of distractors with interior dots. In the second experiment, items in the display were scaled so that the display contained different-sized targets and distractors. In the third experiment, circles rather than squares were used in the display. In the fourth experiment, the circles from the third experiment were distorted to form irregular ellipse shapes. Different subjects performed the task for each of the experiments. In each experiment subjects were able to make an accurate first saccade to the target with a dot outside it. The findings are discussed with reference to theories which advocate that the perception of global topological properties is a general and primitive function of the visual system (Chen, 1982 *Science* **218** 699–700).

◆ **Absolute and relative spatial positions are judged independently**
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For physically interacting with an object in our surrounding, we have to know its absolute position relative to ourselves. To derive this position from visual information we have to consider the orientation of our eyes. For many aspects of vision, such as judging an object's colour, there is no need to consider eye orientation. This is also the case for most judgments of relative positions. To determine whether eye orientation is indeed taken into account for judging absolute positions, but not for judging relative positions, we flashed two targets, with a 67 ms interval between them, while the subject was pursuing a moving dot. Eye-movement recordings enabled us to present the targets at specified retinal locations. We also presented single targets. As expected, subjects indicated the positions of single targets reasonably accurately, with a consistent bias

in the direction of the eye movement. Nonetheless, when two targets were flashed, the indicated separation between them coincided with their retinal separation, rather than with their actual separation, which was much larger. We conclude that absolute and relative spatial positions are estimated independently, on the basis of different types of information.

◆ **Effects of image rotation and scaling on eye-movement pattern**
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We compared eye-movement (EM) patterns of subjects viewing pictures for short periods of time. Each image stimulus was viewed in its original appearance and under two transformations—rotation by 180° and scaling down by an integral factor of two. EM patterns for the original and transformed images were compared in terms of similarity in positions of fixations (Sp) and their sequences (Ss). The stimuli came from four distinct groups: (i) 'pseudo-natural' images that have typical natural-image Fourier power distributions ($1/f$), but with random phase, creating cloud-like patterns without particular shape outlines; (ii) single objects that might appear in the environment in almost any orientation, not possessing intrinsic polarity such as 'up' and 'down' (for example a bundle of keys); (iii) single objects with well-defined polarity (for example a tree); and (iv) scenes with multiple objects and well-defined polarity (for example a picture of a room). The effects of transformations for each category on EM patterns were documented with the use of the Sp and Ss similarities for individual subjects. Significant differences in EM patterns created by the transformations were found, contrary to the predictions of several 'bottom–up' based models in the literature.

◆ **Effects of a residual signal of saccadic eye movement on perceived direction of visual motion**
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Execution of a saccadic eye movement influences performance of oculomotor system and this influence remains even after the saccade ends (Nichols and Sparks, 1995 *Journal of Neurophysiology* **73** 431–435; Schlag et al, 1998 *Journal of Neurophysiology* **79** 903–910). We examined in this study perceptual consequences of this residual signal of saccadic eye movement on perceived direction of visual motion. Human subjects were instructed to follow a visual target produced by a laser in an otherwise completely dark room. After a variable delay immediately after the offset of centripetal saccades, the target moved 10 deg upward from the centre with a variable inclination. The perceived direction of the target movement was then recalled by matching with a jog-shuttle the inclination of a line produced by the same laser. The interval from the offset of centripetal saccade to the onset of target motion, the direction of the centripetal saccade, and the amount of inclination of target motion were manipulated. There was a systematic error in perceived direction of target motion depending on the direction of the centripetal saccade, indicating that the effect was independent of saccadic suppression, and that the residual signal of saccadic eye movement has a new role in motion perception.

◆ **Simulated roll and simulated pursuit affect perceived heading differently**
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Horizontal eye rotation changes the retinal flow pattern; it shifts the centre of flow (CF) relative to the heading direction. Extraretinal and motion-parallax signals compensate for this shift and reduce heading errors. We investigated whether this also holds for roll about the line of sight, and whether the errors for roll and horizontal pursuit interact. The stationary eye was presented retinal flow as if translating (1 m s^{-1}) in various directions towards a cloud or a wall at matched distances of 7 m. Simultaneously, eye rotation was simulated: 2 deg s^{-1} horizontal pursuit, 8 deg s^{-1} eye roll, or the combination thereof. During horizontal rotation, we found larger heading errors for the wall than for the cloud, but still less than the CF shift (15 deg). In contrast, errors during roll were far smaller (< 2 deg) than the CF shift (13 deg) and were not significantly affected by depth. Moreover, simulated roll did not affect the compensation for simulated pursuit. We conclude that, unlike the compensation for horizontal pursuit, the compensation for roll need not rely on an extraretinal signal or on motion parallax. Furthermore, roll does not influence the compensation for pursuit.

ILLUSIONS

◆ **Exploring the causes of the Kanizsa amodal shrinkage**

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To honour Kanizsa in his home town, we explored the causes of amodal shrinkage of the illusion that bears his name. We hypothesised that the shrinkage is due to a correction for directional distortion produced by a 3-D mechanism that fits the two monocular views into a cyclopean one by horizontally displacing and compressing a portion of the visual field. The idea is that the pictorial cue of occlusion triggers this correction, providing veridical 3-D perception but a 2-D illusion. Consistent with this hypothesis, we found that the Kanizsa illusion is reduced in size when the stimulus is presented (a) in 3-D, (b) in 2-D but rotated 90°, and (c) in 2-D with a very narrow bar as an occluder. Moreover, we found that early-enucleated observers experience a reduction in the shrinkage equivalent to that seen by binocular observers in 3-D.

◆ **The (illusory) perception of visual detail: texture and faces**

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Perceptual experience is rich with detail. Perhaps too rich. Visual textures and human faces are two examples of 'objects' which require a lot of information to encode in detail. It is argued that in several illusions the perception of visual detail is often 'quasi-modal' in the sense that it is perceptually experienced without being accurately 'seen.' These illusions might be construed as effects of biological image compression. The first illusion is a texture-density aftereffect, which produces large local distortions in the perceived density (and, hence, numerosity) of textures. I have developed a physiologically plausible computational model of how the density of texture is normally registered. The model is motivated by psychophysical findings in density adaptation including interocular transfer, contingent adaptation, broad spatial-frequency tuning, blind-spot interpolation, and comparisons with contrast and brightness aftereffects. I review these findings in order to show that texture density acts like second-order contrast, and can be modelled by divisive normalisation applied to simulated complex cells. Inasmuch as the evidence suggests that texture density is encoded as a scalar variable, our conscious experience of detail in texture perception is probably an illusion, though a harmless one. Illusions of detail are also illustrated for faces and other objects.

◆ **Illusory deformation of moving contours**

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The absence of motion blur in the perception of moving images and the impressive capacity to predict trajectories of rapidly moving objects demonstrate a surprising precision of the human brain in visual-motion processing. In order to study the interaction between motion and position, we investigated the perceived curvature of short lines and Vernier targets consisting of three dots. We found that a physically straight moving line can appear as if the central region was moving in advance of the line endings. Furthermore, in a three-dot Vernier configuration this illusory deformation depends on the contrast of individual dots. In particular, the perceived deformation is inverted when the flanking dots are brighter than the central dot—now the ends of the three-dot Vernier seem to move ahead and the central dot appears to be trailing. This indicates that the illusory deformation reported here results from misjudging the relative position of components of such simple motion stimuli, and depends on the contrast of the components. If visibility is a critical factor influencing the perceived position of objects or object components along the motion trajectory, possible mechanisms to extrapolate the position of moving targets have to cope with severe performance limitations.

◆ **Competition between static and dynamic organisations in apparent motion**

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In dynamic displays, successive adjacent elements tend to be linked and are perceived as objects in apparent motion (AM). This propensity to be linked in AM is called affinity [Ullman, 1979 *The Interpretation of Visual Motion* (Harvard, MA: MIT Press)]. In static visual displays, adjacent

elements tend to be grouped together and are perceived as virtual objects. This propensity to group is called attraction (Kubovy et al, 1998 *Cognitive Psychology* **35** 71–98). It was commonly thought that grouping by attraction is not influenced by, and therefore precedes, grouping by affinity. We used successive regular dot patterns, called motion lattices, and manipulated the proximity of dots within and between the frames of an AM display. We found that grouping by attraction competes with grouping by affinity: When affinity is stronger than attraction, then the dots are not integrated into a single moving object, and therefore matching is determined by element-by-element correspondence. When attraction is stronger than affinity, then the dots are grouped into a single virtual line, and the dominant direction of motion is orthogonal to the moving line.

◆ **Representational momentum in Michotte's 'launching effect' and 'tool effect' paradigms**
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Observers viewed animated displays in which stimuli collided with targets and 'launched' those targets into motion [cf Michotte, 1963 *The Perception of Causality* (New York: Basic Books)]; launching stimuli were either single objects or a sequence of two objects. Representational momentum [ie displacement of remembered target position in the direction of target motion (Hubbard, 1995 *Psychonomic Bulletin & Review* **2** 322–338)] of launched targets and the second launching objects was measured. Consideration of the 'launching effect' suggests that launched targets should exhibit greater representational momentum than control targets that were not launched, and consideration of the 'tool effect' [Michotte, 1951, reprinted in Thinès et al, 1992 *Michotte's Experimental Phenomenology of Perception* (Hillsdale, NJ: Lawrence Erlbaum Associates)] suggests the presence of a second launching object should not influence representational momentum of the target. Displacements between actual and remembered position were larger for (a) targets launched by two objects than by one object, (b) the second launching object than for targets, (c) control targets that were not launched, and (d) targets for which launching stimuli were in the left visual field. Implications of the data for the 'launching effect', 'tool effect', and representational momentum are discussed.

◆ **Visually induced disorientation**
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We have measured illusory body tilt induced in subjects in various orientations within a furnished room that can be rotated 90° or 180° about a horizontal axis. We have revealed new and dramatic disorientation effects. For example, a supine subject was placed in a room pitched 90° so that the wall above was the one seen when the subject was erect. This induces the illusion that the room and self are erect and creates a compelling sense of weightlessness when the arms or legs are lifted. The proportion of subjects experiencing this illusion increased from about 20% in 10-year olds to 80% in 70-year olds. In a second series of experiments, supine subjects viewed a scene through a mirror set at 45°. All subjects saw a normal scene as erect and a blank surface as a ceiling. We have explored the minimum visual cues to the direction of gravity that induce the reorientation illusion. These include the cue of intrinsic polarity in familiar objects with recognisable tops and bottoms, and that of extrinsic polarity, arising from object support and hanging objects.

◆ **The unconscious sensorimotor visual map**
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The Roelofs effect can separate cognitive and sensorimotor maps of visual space: a target is presented inside a frame that can be presented at 1 of 3 positions: deviated left, centred, or deviated right. Target location is misperceived in the direction opposite the deviation of the frame. If response occurs in darkness immediately after target and frame offset, the Roelofs effect appears for a verbal measure (cognitive) but not for a jab with a finger at the target (sensorimotor), indicating that motor response is controlled by a representation of space distinct from the perceptual representation. One explanation for this capability is that subjects fixate the target and then jab where they are fixating. This explanation suggests a 0-D motor map, a matching of oculomotor and skeletal responses. By monitoring eye movements and instructing subjects to fixate only points on the frame, we found that subjects could jab the target without a Roelofs effect, even when they were prevented from ever fixating the target during the exposure

period. The result indicates the existence of a 2-D motor map of visual space in the brain, used in controlling visually guided behaviour but sometimes holding information contradictory to perceptual information.

◆ **Perceived asynchronies of simultaneous changes along multiple feature dimensions**
D Rose (Department of Psychology, University of Surrey, Guildford, Surrey GU2 5XH, UK; fax: +44 148 325 9553; e-mail: d.rose@surrey.ac.uk)

Recent research on perceived simultaneity of changes in different features of a visual stimulus has indicated a dramatic lack of binding between the changes (Moutoussis and Zeki, 1997 *Proceedings of the Royal Society B* **264** 393–399, 1407–1414). They reported that simultaneous changes in (any pairing of) colour, motion direction, and orientation appear asynchronous. The magnitude of the effect can be as much as 120 ms. Zeki and Bartels (1998 *Society for Neuroscience. Abstracts* **24** 1250), however, found that brightness changes are seen synchronously with colour changes, and depth synchronously with motion. In fact, dissociations of processing time are already well known from experiments on simple reaction time and on the integration of information from different spatial frequencies. Selective attention can also influence the speed of processing. In the present experiments, the perceived simultaneity of changes in (pairs of) colour, motion, and brightness features have been measured with a 2AFC method of constant stimulus technique. The parameters that affect the magnitudes of the illusory asynchronies are explored. The results have important implications for Zeki's theory that awareness of each stimulus dimension arises independently in separate cortical modules, and Dennett's theory [1991 *Consciousness Explained* (Harmondsworth, Middx: Penguin)] of asynchronous processing in the brain.

◆ **ShowTime: A QuickTime-based infrastructure for vision research displays**
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Modern computer-controlled raster displays allow precise control of arbitrary distributions of light over space, time, and colour, and have consequently become the standard display for vision research. A number of software systems have been developed that control raster displays in a manner suited to vision research. However, such systems are often limited to a narrow range of possible stimuli, or require excessive programming effort. All suffer from platform dependence, and are at risk of obsolescence as computer hardware and operating systems mature. The vision community is too small to create an up-to-date, platform-independent, high-level, general software infrastructure for visual displays. But by exploiting an existing commercial software infrastructure we may come close to that goal. QuickTime is a multimedia software architecture developed by Apple Computer and available on several computer platforms, including Apple Macintosh, Windows, and Silicon Graphics. It consists primarily of a file format and an application-programming interface, and is designed to simplify the manipulation and presentation of time-based media, notably video, animated graphics, and sound. Here I describe the advantages of QuickTime for vision research, and also describe a particular psychophysical display system, called ShowTime, based on this infrastructure. ShowTime software is available for free download at http://vision.arc.nasa.gov/showtime/.

BINOCULAR VISION AND STEREO

◆ **Reversed stereo depth and motion direction with anticorrelated 1-D noise**
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Separate studies have revealed that anticorrelated random-dot stimuli are perceived in the 'wrong' direction when displayed in motion, but with no consistent depth when displayed stereoscopically. Here we compared performance on anticorrelated stereograms and kinematograms using the same images and subjects. We generated 1-D and 2-D noise stimuli in which motion/disparity was introduced through a horizontal displacement of the whole image (1.5 deg × 1.5 deg window). Direction/depth discrimination was measured for a range of displacements with stimuli spanning 1, 2, 3, or 5 octaves, all centred on 2.6 cycles deg^{-1} with each octave containing equal power. For 1-D stimuli, psychometric functions for anticorrelated stereograms and kinematograms were very similar, consistently below chance in all conditions. The location of peaks in the cross-correlation function of anticorrelated stimuli varies with spatial frequency, but our results suggest that this conflict does not destroy either motion or disparity detection. With 2-D uncorrelated stimuli the stereo results were unchanged, but the perception of reversed motion was enhanced. We conclude that the key difference between the motion and stereo correspondence problems concerns the integration of information at different orientations. Presenting the stimuli on an anticorrelated zero-disparity background impaired performance on all tasks and abolished stereo depth.

◆ **Binocular motion signals: combined but not perceived**
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The perception of depth from binocular disparity is not possible for anticorrelated random-dot stereograms (bright dots in one monocular half-image, dark dots in the other). Instead, the stimuli are seen as rivalrous and appear not to be binocularly combined. When opposite monocular motion signals are combined, the resulting *z*-motion is harder to detect than the monocular components (Harris et al, 1998 *Nature Neuroscience* **1** 165–168). Does the deficit in performance disappear when stimuli are anticorrelated? Stimuli comprised black and white distractor dots arranged randomly in a 3-D cloud. Stereograms were correlated (dots perceived in depth) or anticorrelated (resulting in rivalry, not depth). We measured detection of a moving target dot amidst stationary distractors. As before, detection of *z*-motion was poorer than that of *x*-motion for correlated stimuli. For two out of three observers, this deficit was maintained for anticorrelated stimuli, despite there being no depth perceived in the distractors or the moving target. At some level the monocular motion signals combine, but this combination does not support 3-D motion perception. This is consistent with neurophysiology [Cumming and Parker, 1997 *Nature (London)* **389** 280–283]: cortical V1 neurons respond to depth changes in anticorrelated stereograms that are not detected by observers.

◆ **The dichoptic perception of achromatic transparency**
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The ability of observers to perceive transparency binocularly (in the absence of explicit monocular transparency cues, such as X-junctions) was investigated. A 6-luminance stimulus, used previously in unpublished experiments by W Gerbino (personal communication), was generated. The stimulus consisted of two concentric circles each divided into three equal sectors, producing an illusory transparent layer (inner circle with luminances *P*, *Q*, and *S*) on a tripartite background (outer annulus with luminances *A*, *B*, and *C*). Layer luminances (*P*, *Q*, *S*) were calculated according to the luminance episcotister transparency model. The subjects' task in all conditions was to adjust the luminance *S*, such that the transparent layer formed a contiguous disk with uniform transmissive and reflective characteristics on the tripartite background. Subjects' performance according to the model was compared across the following conditions: a non-dichoptic binocular condition with no disparities; a dichoptic condition where the inner circle (*P*, *Q*, *S*) was presented to one eye and the outer annulus (*A*, *B*, *C*) to the other; and a set of control conditions. The results suggest that the visual system is capable of making reasonably accurate judgments even when the transparent percept is purely cyclopean.

◆ **Conflicting accommodation can reduce the amount of depth scaling from vergence and differential perspective cues**
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Previous studies of depth scaling from binocular disparities have shown that the extent of constancy is affected by stimulus size, perceptual task, and available distance information, but is typically less than 75% even when these factors are optimised (Glennerster et al, 1997 *Vision Research* **36** 3441–3456). We investigated the role of accommodation in depth scaling. Observers estimated the depth created by a disparity step (10 or 20 min of arc) in a random-dot display which was surrounded by a coarsely textured pattern extending to 80 deg in diameter. Observers viewed the screen from either 29, 57, 114, or 228 cm with the angular size of the display held constant. At each viewing distance, differential perspective and vergence cues were manipulated to simulate viewing distances from 29 cm to infinity. Constancy was typically between 50% and 75% when the accommodation, differential perspective, and vergence cues were all compatible. Conflicting accommodation reduced constancy by ~20% for the majority of observers, but for some the reduction was minimal. We conclude that the presence of conflicting accommodation can have a significant effect on depth scaling and this may have contributed to the reduced constancy found in previous experiments.

◆ **Evidence for polar analysis in binocular and motion parallax displays**
W Gerbino, M Cammaroto (Department of Psychology, University of Trieste, via dell' Università 7, I 34123 Trieste, Italy; fax +39 040 301 867; e-mail: gerbino@univ.trieste.it)
Two experiments were performed to estimate relative depths of convex truncated cones and concave tubes generated by two-circle displays commonly used to demonstrate the stereokinetic effect. In the first experiment, observers estimated depths of cones and tubes perceived in stereoscopic displays with different amounts of horizontal disparity. The relative depth estimated in uncrossed-disparity tubes was larger than the one estimated in crossed-disparity cones. The depth difference increased as the size of the inner circle decreased. This can be explained by: (i) polar analysis of stereograms; (ii) a tendency to perceive concave volumes as cylinders. In the second experiment, observers modified the horizontal disparity of a binocular two-circle display to match the depth perceived in a monocular stereokinetic two-circle display. Stereokinetic information was conveyed by the horizontal relative translation of the two circles. The depth difference between the stereokinetic cone and the stereokinetic tube was larger than expected on the basis of estimates obtained in the first experiment, suggesting that the tendency to rectify concave volumes and perceive them as cylinders is stronger in stereokinesis than in stereoscopy.

◆ **Stereo-depth aliasing**
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A fundamental problem in stereo processing is determining which images in the two eyes correspond to the same object, ie the correspondence problem. This problem is particularly pronounced for periodic stimuli. Experiments were conducted to compare the propensity of the sustained and transient systems to exhibit depth aliasing—that is to signal depth in the opposite direction to that which corresponded to the nearest-neighbour binocular match. Stimuli were large-field luminance gratings. The transient and sustained systems were selectively driven by using either a short (140 ms) or a long (9 s within a cosine temporal envelope) stimulus duration. Results were: depth aliasing was exhibited at short, but not at long duration; decreasing the disparity of the stimulus reduced the likelihood of depth-aliasing; and the critical disparity for this reduction in depth aliasing was dependent upon the spatial frequency of the stimulus, ie it was dependent on phase, not absolute disparity. On the basis of these results, we conclude that while the sustained system implements a half-cycle disparity-processing limit, the transient system does not.

◆ **Adaptation to shape, not disparity**
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Prolonged viewing of a surface curved in depth causes a subsequently viewed flat surface to appear curved in the opposite direction. Such aftereffects have previously been attributed to disparity mechanisms. Another possibility is that depth aftereffects are due to higher-order mechanisms based on perceived shape, independent of horizontal disparity. To recover stereoscopic depth from horizontal retinal disparities, information about the prevailing viewing geometry is required. For example, the pattern of horizontal disparities giving rise to the percept of a flat surface at a one viewing distance will produce a percept of a curved surface at a different viewing distance. If aftereffects are based on disparity alone, then adaptation to identical sets of retinal disparities at two different viewing distances will produce the same depth aftereffects at a single test distance. In contrast, if adaptation is based on higher-order shape mechanisms, then adapting to identical retinal disparities at two different viewing distances will produce different depth aftereffects at the test distance. We manipulated viewing distance by varying the vergence angle while keeping retinal disparities constant. The results suggest that curvature aftereffects are dependent upon shape rather than disparity.

◆ **Monocular symmetry is neither necessary nor sufficient for dichoptic symmetry perception**
P Wenderoth (Department of Psychology, Macquarie University, Sydney, NSW 2109, Australia; fax: +61 2 9850 9238 or 9850 9390; e-mail: peterw@vision.bhs.mq.edu.au; WWW: http://vision.bhs.mq.edu.au/~peterw)
Barlow and Reeves (1979 *Vision Research* **19** 783–793) showed that bilateral symmetry detection in dot patterns is about equally efficient whether the displays are viewed monocularly or binocularly. If there is an OR-gate binocular process, this experiment does not indicate whether symmetry detection occurs before or after the site of binocular integration. This is so because the symmetrical patterns would have stimulated both monocular and binocular mechanisms under both viewing conditions. We presented stereoscopic 20-dot patterns, 10 dots to each eye, for 150 ms so that 'false fusion' rather than rivalry occurred. Any axis of symmetry in the patterns was oriented

at vertical (90°) or ±1°, 2°, 3°, or 4° from vertical. The task was to judge whether the axis was tilted left or right of vertical, by the method of constant stimulus differences. Three kinds of pattern were used: SSS patterns were symmetrical in each eye alone and also dichoptically; RRS patterns were nonsymmetrical monocularly but dichoptically symmetrical; and SSR patterns were symmetrical monocularly but dichoptically nonsymmetrical. Orientation judgments were accurate, and equally so, for SSS and RRS displays but were extremely poor under SSR conditions. Thus, monocular symmetry is neither necessary nor sufficient for dichoptic bilateral symmetry perception.

THURSDAY

SYMPOSIUM

MOTION TRANSPARENCY

◆ **Questions about motion transparency**

O J Braddick (Visual Development Unit, Department of Psychology, University College London, Gower Street, London WC1E 6BT, UK; e-mail: ucjtsol@ucl.ac.uk; WWW: http://vdu.psychol.ucl.ac.uk/vdu/ol.html)

Motion transparency involves seeing two motions located in the same region of the visual field. The phenomenon poses many questions, some of which are addressed in this symposium. To understand motion transparency, there appear to be at least three levels at which we need to understand the underlying representation: (a) a local level (V5 subunits?) at which only a single motion value can be represented at each location [*Questions*: Why doesn't this happen at V1? Do the interactions which locally suppress other motions occur within, or between, elementary motion detectors?]; (b) a more global scale (V5 receptive fields?) at which the distribution of velocities in a region can be represented; various percepts, including transparency, can be derived from this distribution [*Questions*: What rules determine parsing of this distribution into multiple vs single motions? How flexible is the region over which this computation is done? What is the relation between parsing 'additive' transparency (eg lacy partial occlusion; experiments with random-dot kinematograms) and 'multiplicative' transparency (eg shadows and partially transmitting surfaces; experiments with plaids)?]; (c) a level of representation at which motions are associated with objects or surfaces, rather than with locations or field regions [*Questions*: What could be the neural basis of such a representation? Is it this level that limits the number of transparent surfaces that can be perceived?].

◆ **Perceived motion direction and speed of locally balanced stimuli**

W Curran, O J Braddick (Department of Psychology, University College London, Gower Street, London WC1E 6BT, England; fax: +44 171 380 7576; e-mail: w.curran@psychol.ucl.ac.uk)

Phenomenal transparency in random-dot kinematograms is abolished when two motion directions are 'locally balanced' by pairing limited-lifetime dots at each location. This has been attributed to local inhibition between motion detectors more than 45° apart (Qian et al, 1994 *Journal of Neuroscience* **14** 7357–7366). We investigated perceived motion in such displays, by requiring subjects to make direction and speed judgments with locally balanced stimuli containing two directions 60°, 90°, or 120° apart. Subjects perceived coherent motion in these displays and made reliable direction judgments, indicating that the two motions are combined rather than interfering destructively. Judged motion is in the vector-average direction of the two components. This vector-averaging rule also applies when the two sets of component dots differ in their velocity. Similarly, speed judgments comply with a vector-averaging rule for a range of speeds as well as for mixed-speed stimuli. These results suggest that the abolition of transparency does not necessarily imply abolition of a global motion percept. The local interaction abolishing transparency is not exclusively inhibitory, at least for directions up to 120° apart, but generates a vector combination of the superimposed motions. Whether this interaction occurs within, or between, elementary motion detectors requires further investigation.

◆ **Motion transparency of complex gratings depends on phase congruency of Fourier components**

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The motion perceptual system is extremely versatile, capable both of integrating information to create a unified impression of coherent motion, or segregating information to create the perception of transparency. This can be particularly problematic when the individual elements are spatially superimposed, such as the sinusoidal gratings that are harmonics of a complex waveform. For example, two such gratings moving in opposite directions are seen as a single static grating modulated sinusoidally in time (counterphased). However, two square-wave gratings drifting in opposite directions are seen to move independently in transparency. What determines whether transparency is seen or not? I present a series of studies showing that phase congruency between spatiotemporal Fourier components can organise the perceptual structure of the image and its motion. Changing the phase of the fundamental component of a complex waveform creates the perception of transparent motion of this component over the other harmonics. In counterphased square-waves this effect is so strong that illusory motion is induced in an otherwise stationary flickering pattern. In all cases studied, changing the relative phase induces a reorganisation of image features, suggesting that a feature-tracking process may underlie the perception of motion transparency. It is further shown that a model (Del Viva and Morrone, 1998 *Vision Research* **38** 3633–3653) based on feature tracking explains the results, qualitatively and quantitatively.

◆ **MT cell responses to transparent motion patterns predict misperception of metameric stimuli**
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We recorded responses of direction-selective cells in area MT of the visual cortex of a macaque monkey to random-dot patterns (RDPs) made up of two groups of dots forming various component angles between their respective directions. We determined the response profiles of the cells to these patterns to estimate the population activity (PA) across direction-selective cells for bivectorial motion. The observed PA was well predicted by the scaled sum of the responses to the individual component motions. Given the broad tuning curves of direction-selective neurons to single directions, the PA was single-lobed for RDPs with acute ($< 90°$) component angles. It is thus impossible to recover the angles from distinct peaks in the PA. Rather, the visual system has to take the width or even the whole shape of the PA into account. Such an approach is a robust way of recovering two components but would make the system susceptible to metamers, ie stimuli that create the same PA from several motion components of unequal strength. We confirmed this prediction in humans by creating RDPs containing 3 or 5 appropriately selected motion components that were perceived as containing only the 2 components predicted from an approach that evaluates the overall shape or width of the PA.
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◆ **Multiple processing of motion energy in different directions and its relation to induced motion and motion capture**
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Possible mechanisms for motion transparency include feature tracking, multiple spatial-frequency channels, luminance-based transparency rules, and motion energy. Mulligan (1993 *Vision Research* **33** 2021–2030) introduced a critical stimulus consisting of superimposed dense random-dot patterns. The motion transparency perceived in this stimulus is not explained by feature tracking or multiple spatial-frequency channels. Using this stimulus, I found that the occurrence of motion transparency depends on three luminance levels assigned to three possible combinations of component dots: (1) white dots superimposed on white dots, (2) white dots on black dots, and (3) black dots on black dots. Interestingly, the motion-energy model (Adelson and Bergen, 1985 *Journal of the Optical Society of America A* **2** 284–299), not physical rules of luminance-based transparency (eg Metelli, 1974 *Scientific American* **230** 90–98), quantitatively predicted the human performance, supporting the idea by Qian et al (1994 *Journal of Neuroscience* **14** 7357–7366) that motion-energy detection followed by spatial integration is an underlying mechanism of motion transparency. Next, I found that induced motion in a static stimulus superimposed upon motion-transparency display is described as the opposite to the vector sum of component directions, but the direction of motion capture is determined by the perceived depth order of motion transparency, suggesting that induced motion is processed earlier, and motion capture occurs later, than the process for motion transparency.

◆ **Can non-motion cues contribute to the segmentation of different motions?**
R J Snowden (School of Psychology, Cardiff University, Cardiff CF1 3YG, UK; fax +44 1222 874 858; e-mail: snowden@cardiff.ac.uk; WWW: http://www.cf.ac.uk/uwc/psych/Snowden/)
Motion transparency requires the integration of some motion signals whilst separating other motion signals. In theory, one might use other image qualities, such as colour and depth, to provide further evidence which signals should be integrated and which should be segmented. I discuss both psychophysical and physiological evidence for the influence of non-motion cues upon the detection of coherent motion and motion transparency. Recent data suggest that depth cues from retinal disparity are most useful in motion segmentation, whilst the influence of colour cues is still questionable. Why these two types of cue might have differing effects is a question of central interest.

◆ **Motion transparency and its aftereffect(s)**
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Transparent motion has proven to be an excellent stimulus to investigate the neural mechanisms underlying motion perception. One way to explore these mechanisms is by using motion aftereffects (MAEs). The MAE of transparent motion was thought to be an integrative phenomenon: after

adaptation to transparent motion in which two superimposed surfaces of random dots are moving in orthogonal directions, the MAE is unidirectional and opposite to the vector sum of both inducing directions. Recently, we have shown that the direction of this MAE is highly dependent on the velocity of the inducing patterns and especially the nature of the test pattern. For the same adaptation stimulus the direction could differ as much a 50° for a static and a dynamic test pattern. We explored this phenomenon in more detail and found that it is highly likely that two different motion-sensor populations underlie the effect. These populations are easily distinguishable in the temporal domain. Adaptation to a stimulus designed to show both populations results in a persuasive behavioural correlate, a transparent-motion aftereffect. The results imply that there are several gain controls along the pathway of motion processing and the way they show themselves in the MAE strongly depends on the test conditions.
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◆ **Attentional selection in transparent motion**
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WWW: http://www-psychology.concordia.ca/department/CVLab/CVLab.html)
In transparent motion, two or more directions of motion occur simultaneously in the same spatial region. These may define different depth layers, changing their depth ordering in some stochastic way during prolonged inspection. We have shown that with directed attention we can select one motion direction of a plaid stimulus and keep it as the front layer. This affects motion-aftereffect duration, increasing it for the selected component, and decreasing it for the simultaneously ignored component. We have also looked at transparent motion of two different flow fields, radial and planar. The fields consist of large (100 deg × 100 deg) dot displays with controlled density, lifetime, and coherence. We have measured coherence thresholds of the selected field in the presence of the other. Planar flow fields are more affected by the radial fields than vice versa. This effect also depends on the relative velocity of the two fields in such a way that maximum interference by the radial on the planar field occurs when the planar velocity matches the velocity of the more peripheral parts of the radial fields. These effects are interpreted in terms of different motion mechanisms at striate and extrastriate levels.

◆ **Modelling motion transparency**
A Johnston (Department of Psychology, University College London, Gower Street, London WC1E 6BT, UK; fax: +44 171 436 4276; e-mail: a.johnston@ucl.ac.uk)
Many biological models of motion analysis aim to provide a single estimate of the velocity field for each visual direction. Our experience of motion transparency therefore provides a challenge to models of how motion is represented and computed. Central to this question is whether we can see two or more motion vectors at a point in the visual field. If it is possible to see more than one motion at a point, we need to consider how multiple local measures can be computed, and the form of the neural representations required. An alternative is to consider that motion transparency arises from a more global analysis of the pattern or distribution of local motion vectors within a region. The form of the distributions, single peaked or bimodal, could be interpreted as indicating one or two velocities in the region. One problem with this approach is in distinguishing between spatially overlapping, hence transparent, and spatially segregated motion fields. A third approach is to consider that motion transparency results from a more general process of image interpretation, involving high-level grouping and segregation, such as the identification of local measures with moving surfaces. What kinds of computational model do we need to address these issues?

ORAL PRESENTATIONS

BIOLOGICAL MOTION

◆ **Biological motion processing without attention**
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Biological motion processing has been shown to be robust across both space (Bertenthal and Pinto, 1994 *Psychological Science* **5** 221–225) and time (Thornton et al, 1998 *Cognitive Neuropsychology* **15** 535–552). These findings reflect the obvious ecological significance of such stimuli, which can almost certainly recruit routines at both high and low levels of the visual system as particular task demands dictate. In the current work we manipulated attention as a way of exploring the

nature of biological motion processing when a smoothly walking figure was obscured either by (a) a random-dot mask (simple) or (b) a 'scrambled walker' mask (complex). Attention was manipulated by superimposing a change-detection task directly on top of the walker display. Such change-detection tasks require focused attention. In the baseline condition, where observers ignored the change-detection task, direction discrimination was 100% for both types of walker display. However, when attention was given to the change-detection task, complex-mask performance fell to chance while the simple-mask performance was relatively unaffected (80%+). These results suggest that global processing of biological motion may involve some form of attentional tracking or 'active' motion processing (Cavanagh, 1991 *Spatial Vision* **5** 303–309).

◆ **Spatial summation of complex motion**

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Our purpose was to compare the spatial summation properties of simple, complex and structured motion. All motion stimuli (translation, shearing, radial, rotational, and biological motion) comprised moving dots with two-frame limited lifetime, matched in size, density, and velocity. Observers identified the location of the stimulus (detection) and (in separate sessions) the direction of motion or ambulation (discrimination). The stimuli were sampled spatially with a variable number of dots, and sensitivity was determined by the maximum number of added noise dots that could be tolerated.

Sensitivity for all simple and flow-field stimuli increased linearly with signal dot number for both detection and discrimination, consistent with the performance of an ideal integrator. Confirming and extending previous results [Neri et al, 1998 *Nature (London)* **395** 894–896], discrimination of biological motion shows a much steeper summation, with a log–log slope around 3. We conclude that ideal integrators mediate the perception of simple drifting patterns and also of motion along complex trajectories (optic flow), that cannot be achieved by a local analysis alone. However, structure-from-motion seems to be analysed by different mechanisms that have a more flexible coding strategy at the expense of poorer efficiency.

◆ **Contributions of facial and head motion in the interpretation of expression**

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Movement of both the head and the face are used to express emotion and to aid communication. Previous research by Bassili with point-light displays of facial movement indicated that point-light displays of facial movement are sufficient to provide an interpretation of emotion. We investigated how head movements combine with facial movements to obtain an interpretation of expression. A 3-D position analysis system was used to measure 22 locations on the face while an actor displayed expressions of anger, happiness, fear, and sadness. For each expression, the position data were separated into components of head and facial motion. These two separate motion cues were combined in all possible combinations to obtain 16 displays. Pairs of these displays were presented for participants to make dissimilarity judgments. A multidimensional scaling analysis was applied to these data. Results indicated that the happy facial expression dominated when combined with other head movements, whereas the angry head movement dominated over all but the happy facial expression. These results are discussed in the context of the relative strength of these two separate motion cues and their patterns of combination.

◆ **Point-light walker yields greater MEG gamma activity than scrambled or inverted figures**

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Changes in magnetoencephalographic (MEG) gamma activity during biological motion perception have been assessed. Subjects saw a set of 200 displays of two types: a canonical point-light figure and a 'scrambled walker' that consisted of spatially scrambled points on the joints of a canonical one. In separate runs, both configurations (9.3 deg by 6.4 deg) were presented either with an upright or with an inverted display orientation. MEG responses were recorded with a whole-head system. After a blank screen (baseline), a display appeared for 650 ms. Subjects were asked to respond to the second of two consecutive identical stimuli of each type. Only correct trials without motor responses were processed. For both upright and inverted canonical

figures, gamma activity (25–30 Hz) increased over the occipital areas already 100 ms from stimulus onset. It was greater to the upright figure, which also evoked gamma responses over the temporal and parietal areas. Yet, neither upright nor inverted 'scrambled walker' evoked any enhancements in gamma activity. The findings indicate that processing of meaningful coherent structure from motion leads to greater gamma oscillations than the same display presented upside–down. Moreover, non-coherent configurations consisting of the same amount of absolute motion do not yield any enhancement in MEG gamma activity.

◆ **The perception of affect from point-light displays of simple arm movements**
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Point-light displays of human motions, such as walking, are normally recognised very quickly and easily. However, the categorisation of human movements by gender, identity, and emotion have proven more problematic. We investigated the ability to interpret affect from point-light displays of actors performing simple arm movements such as drinking and knocking. The knocking and drinking motions were recorded with the use of a 3-D position analysis system. Two actors were asked to express 10 different affects in their actions while the motion of their head, right hand, wrist, elbow, and shoulder were measured. Participants then viewed these point-light displays and had the task of categorising each motion as one of the 10 affects performed by the actors. The proportion of correct responses was converted into a measure of dissimilarity which was input to a multidimensional scaling analysis. These results suggest that the original 10 expressions can be grouped into approximately 4 groups. The correlates between motion and categorisation are discussed further along with the results from a second experiment in which a free response task was used.

FACES

◆ **An illusion of facial expression perception in Japanese Noh masks**
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With certain masks used in Noh drama, the facial expression appears to vary with vertical viewing angle: tilt the mask forward and it seems to smile, tilt it backwards and it looks sad. A Noh mask was photographed under theatre lighting at inclinations from $-30°$ (backward tilt) to $+30°$ in $5°$ increments. Japanese and British subject pools viewed 300 ms exposures of mask images and classified the expression as happy or sad. For each pool, the averaged response varied smoothly from sad to happy as the mask inclined forward to $+5°$. For Japanese subjects the response then decreased with increasing angle, whereas the British subjects showed a nearly monotonic response. Repeating the experiment with images showing only the internal area of the mask abolished nonmonotonicity of the Japanese subjects, supporting a cultural difference in the interpretation of pose cues. A 3-D scan of a Japanese female posing the Noh mask expression was used to generate control stimuli. Responses showed a view dependence similar to, but less pronounced than, that with the mask. We propose that the Noh mask illusion is created by judicious distortion of a realistic model of the human face to enhance a naturally occurring visual effect.

◆ **Looking for a face in a crowd**
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It is commonly assumed that visual search involves noting both the position and identity of objects in the search scene. Horowitz and Wolfe [1998 *Nature (London)* **357** 575–577] present evidence that this is not the case, and suggest that visual search is 'amnesic'. Rather than using the abstract symbols or letters customarily employed in search tasks, we used faces, thus presenting subjects with a familiar, real-world task: looking for a face in a crowd. On each search, subjects had to say whether the target face was present or absent, and they were presented with both 'static' trials in which the faces swapped positions randomly every 110 ms. These conditions and set size (8, 12, or 16 faces) were randomly intermixed. In both the static and random conditions, the reaction time to correctly identify the presence of the target face increased linearly with the number of distractors, and the slopes are consistent with a serial search process. In addition, we find that search efficiency is similar in the random and static conditions, with a slightly shallower slope in the random condition. These data can be interpreted as supporting the view that visual search is 'amnesic', but other possible interpretations are discussed, including a possible pop-out effect for faces.

◆ **That wide-eyed look: estimating interpupillary distance**
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Our ability to perceive many aspects of the human face is so acute that some would propose that we possess specialised face-processing mechanisms. One example of this exquisite performance is our ability to discriminate differences in the lateral separation of the eyes in pairs of otherwise identical faces (Kemp et al, 1990 *Perception* **19** 531–543). Given such performance it is strange that generations of students express incredulity when told that the mean interpupillary distance is approximately 61 mm for women and 65 mm for men. To investigate this more formally, 80 naïve Caucasian undergraduate students (18 male, 62 female) were asked to indicate, without undue rumination, their own interpupillary distance by marking the separation on a piece of paper. They were also asked to indicate the distance from the bridge to the tip of their own nose. The mean estimated interpupillary distance was 82.4 mm and the length of nose measurement was 42.8 mm. Actual measurements of these two distances were taken for each subject. The results show that while subjects significantly overestimate interpupillary distance (by more than 30%), they show no significant bias in their estimates of nose length. More or less plausible explanations of these findings are discussed.

◆ **Unconscious perception and retrieval of faces imaged with H215O PET**
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This experiment was designed to reveal the neural correlate of conscious perceptual and cognitive processing as opposed to unconscious perceptual and cognitive processing. We recorded the regional cerebral blood flow (rCBF) with H215O PET during the subliminal and supraliminal presentation of faces alone or faces combined with a written profession. A subliminally presented contour of a portrait was presented in the control condition. After each encoding condition, the previously presented faces were shown again with the instruction to guess the profession of the person. Statistical parametric mapping was performed to identify activations underlying conscious and unconscious face encoding, face retrieval, lexical and semantic word processing, and retrieval of previously established associations between faces and professions. The network of activated regions during the conscious was compared with that during the unconscious execution of these cognitive processes. These comparisons showed that unconscious and conscious processing activated an overlapping network of neocortical structures. Compared to conscious processing, areas activated during unconscious processing were smaller and the degree of activation was lower. The locations of rCBF indicate that subjects had unconsciously processed the faces and words up to a semantic level and that they unconsciously remembered the face/profession associations at retrieval.

◆ **The dynamics of facial expression judgments**
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We investigated the dynamics of facial expressions by comparing static and dynamic conditions. In the static condition, we used four basic expressions (happiness, sadness, surprise, and anger). In the dynamic condition we morphed these faces from the neutral expression to one of the four basic expressions, at either a slow, intermediate, or fast rate of change (3.3, 0.9, or 0.2 s). Static pictures were shown for the same duration as the dynamic pictures. The observer judged the expressions (emotional magnitude) at the end of each presentation. Principal component analyses (PCA) revealed that the basic expressions were distributed categorically in multidimensional space. Static faces were randomly distributed around the position in PCA space irrespective of the presentation time. However, for dynamic faces the position in PCA space was highly dependent on the presentation time. According to their position in PCA space, there is a systematic confusion between expressions dependent upon rate of change. 'Happiness' and 'anger' expressions are erroneously

recognised as the expression of 'surprise' when they are presented rapidly, but are confused with 'sadness' if they are presented slowly. The results suggest that the dynamic context affects perceived facial expression.

ATTENTION AND SEARCH I

◆ **Attentional limits across the elements of a complex visual display**

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We have examined the distribution of attention in a complex array. Participants searched for a target in one of two perceptual groups, one moving and one stationary. An arrow cued which group to search. The cue was in the fourth (middle) position of a seven-element vertical array. Elements in the upper three locations moved; those in the lower three locations were stationary. The arrow was an element of either the moving or the stationary group. Thus, target search was within a group (eg cue and target moving) or across groups (eg cue moving, target stationary). Search times were faster when cue and target were in the same perceptual group. This within-group advantage only extended two target locations from the cue; it was absent at the far location. The result occurred in two experiments, one in which the far target location was 3.8 deg from the cue and one in which the far target was 1.9 deg from the cue. Thus, the absence of the within-group search advantage at the far location was not an artifact of retinal eccentricity. This limit on perceptual grouping indicates global and local influences on attention in complex arrays.

◆ **A saliency model for search for motion or colour**

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Last year at ARVO (Rosenholtz, 1998 *Investigative Ophthalmology & Visual Science* **39**(4) S629), I presented a saliency model of motion pop-out. I represent motion of each display element as a point in velocity space, and compute the mean and covariance of the distractor motions. I then replace the distractor distribution with the maximum entropy (in this case, 2-D normal) distribution with the same mean and covariance. Given this estimate of the distractor distribution, target saliency is then related to minus the log-likelihood of observing the target velocity. In the simplest version of the model, the more salient the target, the more efficient the search. I showed that this model predicts a number of well-known motion-search asymmetries. I demonstrate that an equivalent model can also predict a number of results in colour search, including both results typically explained by the linear separability model of D'Zmura (1991 *Vision Research* **31** 951) and Bauer et al (1996 *Vision Research* **36** 1439–1465), and colour asymmetries such as those found by Nagy and Cone (1996 *Vision Research* **36** 2837–2847). I discuss the differences between this model and linear separability, describing the critical experiments for distinguishing between the two models. I also compare the saliency model with Duncan and Humphreys' search surface (1989 *Psychological Review* **96** 433–458).

◆ **Searching for patterns in noise**

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Observers can easily detect a simple pattern of dots amidst random dot noise, particularly if the test pattern appears at a known location [Uttal, 1975 *An Autocorrelation Theory of Form Detection* (Hillsdale, NJ: Lawrence Erlbaum Associates)]. It is much harder to detect the test pattern when it is presented at an unknown location, because the observer must monitor many potential locations to find it. To investigate whether contemporary models of search (Verghese et al, 1999 *Vision Research* **39** 19–30) can account for these results, we measured the detection of an oblique string of five aligned dots presented at an unknown location, as a function of noise density. Observers judged which of two 200 ms intervals contained the signal string. Noise composed of pairs of dots, with the same orientation as the signal, greatly degraded detection compared to random dot noise of the same density. Noise pairs at an orthogonal orientation had almost the same effect as random noise. These results indicate that search for these simple patterns in noise is based on competing responses in oriented filters. We successfully modelled these results with an array of multi-scaled oriented detectors optimally tuned for the signal string.

◆ **Attentional processing of geometric figures**

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Focused attention is needed to perceive change (Rensink et al, 1997 *Psychological Science* **8** 368–373). But how much attentional processing is given to an item? And does this depend on the nature of the task? To answer these questions, 'flicker' displays were designed, in which an

original and a modified image continually alternated, with brief blanks between them. Each image was an array of simple figures, half being horizontal and the other half vertical. In half the trials, one of the items changed orientation; in the remainder, all items remained the same. Observers were asked to detect whether a change was occurring in each trial. Within-observer comparisons for different shapes of items yielded two classes of speed: relatively fast search (ca 50 ms/item) for simple lines, and slower search (ca 90 ms/item) for compound figures made of two or more lines. Evidently, more processing was given to compound figures, even though shape was irrelevant to the task. In a similar set of experiments observers were askedto detect changes in contrast polarity. Here, no differences were found for different shapes, indicating that geometric information is not processed as much when the task involves only nongeometric properties.

◆ **Higher-level summing circuits mediate orientation-based visual search tasks**
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We investigated mechanisms signalling orientation in visual-search tasks. Targets and a variable number of distractors were small, high-contrast circular patches formed by superimposing sinusoidal gratings of 2 and 10 cycles deg^{-1}. Both components of distractor elements were vertically oriented. In each condition, observers searched for either of two targets, each of which was defined by two orientation cues, a 3° tilt off vertical (left or right) in each frequency band. Experimental conditions differed in how directional cues were combined. In the rigid-rotation condition components tilted in the same direction (left in one target, right in the other). In the non-rigid-rotation condition components tilted in opposite directions. Equal performance in the two conditions indicates that the high-frequency and low-frequency components are processed independently; unequal performance indicates mediation by a higher-level combining circuit. Our data indicate faster response times in the rigid-rotation conditions, suggesting that visual searches based on orientation are mediated by a higher-level circuit that sums orientation information over disparate frequency bands. We speculate that this mechanism is the same specialised summing circuit revealed in earlier orientation discrimination experiments (Olzak and Thomas, 1999 *Vision Research* **39** 231–256).

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◆ **Measuring the independence of attention to multiple features**
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Our aim was to determine how much information can be extracted from a single spatial, and attentional, locus. Observers viewed a single Gabor patch which drifted randomly, yet smoothly, in space while simultaneously rotating, changing spatial frequency, and changing colour (in time, between isoluminant grey and red). At some random time, the patch exhibited a slight discontinuity in its motion along all five dimensions (*X*, *Y*, colour, frequency, and orientation) simultaneously; that is, there was a slight 'jump' in the trajectory of the patch. Observers reported the direction of the jump (eg "left" versus "right", "more red" versus "less red"). Jump direction was chosen randomly and independently for each of the dimensions. In any given block of trials, observers reported jump direction for a pair of dimensions. These ten pairwise conditions were further blocked by three different attention instructions: 90% dimension 1 attention, 10% dimension 2 attention; 50%/50% attention; or 10%/90%. Single response control conditions were also run. Almost always, performance on a given dimension, given by the control conditions, was unchanged even when observers concurrently attended to another dimension. This suggests that the attentional resources devoted to monitoring the feature dimensions of a single object can be modelled as independent.

◆ **The role of attention in the flash-lag effect**
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Objects flashed in alignment with moving objects appear to lag behind. Could this 'flash-lag' effect be due to attentional delays in bringing flashed items to perceptual awareness [Titchener, 1908 *Lectures on the Elementary Psychology of Feeling and Attention* (New York: Macmillan)]? We tested this attentional account using Posner's cost–benefit cueing procedure. Observers viewed two horizontal lines moving leftward; one above and one below fixation. An arrow (80% valid) indicated the location of an upcoming flash of a horizontal line adjacent to one of the moving lines.

The horizontal offset of the flashed line relative to the moving line was varied. In a reaction-time task, observers pressed a key to indicate the location of the flashed line. Secondly, observers reported whether the flashed line appeared ahead or behind the moving line (2AFC). Valid pre-cueing resulted in significantly faster responses (~100 ms advantage), verifying that attention was successfully manipulated. However, we found only a negligible difference in the estimated flash-lag effect (calculated as the point of subjective equality of the psychometric functions) for the valid (mean 63.7 ms) and invalid (mean 65.9 ms) conditions. Thus, attention shortens the response time to the pre-cued flash. However, this attentional advantage cannot account for the flash-lag effect.

◆ **Covert attention improves orientation discrimination across the contrast sensitivity function**
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We have reported covert attentional effects on early visual tasks that support the signal-enhancement hypothesis [Carrasco and Yeshurun, 1998 *Journal of Experimental Psychology: Human Perception and Performance* **24** 673–692; Yeshurun and Carrasco, 1998 *Nature (London)* **396** 72–75; Yeshurun and Carrasco, 1999 *Vision Research* **39** 293–305]. Here, we explore whether peripheral attention improves orientation discrimination for Gabor patches spanning the contrast sensitivity function. In a 2AFC task, observers indicated whether a target presented in isolation was oriented vertically or horizontally. The target (0.5 to 16 cycles deg^{-1}) appeared at 1 of 8 possible equidistant locations (2.5 to 6 deg of eccentricity). Each trial began with either a 40 ms peripheral (small circle adjacent to the target location) or neutral (a circle in the middle of the display) cue. After a brief ISI, the display appeared for 100 ms. A random mask followed half the displays. Threshold was assessed by a QUEST symmetrical-estimation procedure. Precueing target location lowered the discrimination threshold for Gabor patches of all frequencies and eccentricities tested, regardless of the presence of the mask. When a field asymmetry emerged—performance was higher for the lower than the upper visual field—it did so for both cued and neutral trials; the attentional effect was similar across visual fields. These results support the signal-enhancement hypothesis.

ATTENTION AND SEARCH II

◆ **The perceptual amplification of attention to colour**
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How does attending to a colour enhance perceptual processing of that colour? One facet of this complex problem was addressed in an ambiguous motion paradigm [Lu and Sperling, 1995 *Nature (London)* **377** 237–239]. A rapid sequence of frames is presented to a subject: odd-number frames are red–green isoluminant gratings; even-number frames are texture contrast-modulated gratings; all on a yellow background. Normally no motion is seen in these displays. However, making one colour more different from the background (while keeping the grating isoluminant) causes motion to be seen in the direction of that colour. Instructions to attend to a colour, as measured in motion direction discrimination, are equivalent to increasing the saturation of that colour. The appearance of a grating, however, does not change with attention. A quite complex set of data describing the effects of attention instructions as a function of chromatic mixture and spatial frequency are encapsulated (99% of variance predicted) by a simple linear-system model in which attention amplifies the 'salience' that is computed for a colour input but not the colour itself. Attention amplification, which varies from 1.25 to 2.17 is found to depend on the observer and the attended colour, but not on spatial frequency or colour composition of the stimulus.

◆ **Withdrawal of attention has greater effects on adaptation to high spatial, low temporal, frequencies**
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We studied the effects of attention on the spatial and temporal scale of visual analysis by measuring the duration of movement aftereffects produced by adaptation to drifting sinusoidal gratings of a range of spatial (0.5, 2, 4, and 6 cycles deg^{-1}) and temporal (1.5 and 10 Hz) frequencies, diverting the subjects' attention by having them name the changing digits which formed the fixation point [Chaudhuri, 1990 *Nature (London)* **344** 60–62]. With undiverted attention, aftereffect durations declined with spatial frequency for the 10 Hz stimuli, and rose with spatial frequency for the 1.5 Hz stimuli. Diverting attention from the 1.5 Hz stimuli had almost no effect at 0.5 cycle deg^{-1}, but led to a progressive reduction in MAE duration with increasing spatial frequency, reaching about 66% at 6 cycles deg^{-1}. Diverting attention from the 10 Hz stimuli had similar effects at all spatial frequencies. Thus the effects of diverting attention are least for coarse, slowly moving,

stimuli, suggesting that a crude spatial and temporal analysis occurs even for ignored stimuli, but that finer analysis requires attention.

◆ **Reverse Stroop interference effect**

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In the classical Stroop effect, colour naming is retarded if the colour name does not correspond to the actual stimulus colour. This is a very robust effect. In the experiments reported here we have measured a reverse effect: the reading of a colour name can be influenced by the colour of the word. This effect is obtained by retardation of the reading process. An effective way to obstruct the (automatic and fast) reading process is to present the colour words as isoluminous stimuli. Surprisingly enough, in the Stroop-effect literature there are no reports of the influence of retardation by either blur or isoluminance or other stimulus degrading techniques. The standard procedures for Stroop tests have been followed. Consistent colour names and colours, inconsistent colour names and colours, neutral words with the same colours, all under isoluminous or non-isoluminous conditions. As a relevant measure for the interference effect, we introduced a kind of contrast measure, analogous to Michelson contrast. We did indeed find a reversal of the Stroop interference effect: reading of a colour word is influenced by the colour of the word.

◆ **The effect of attention on orientation thresholds for location and discrimination of oriented targets amongst vertical and tilted distractors**

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We measured orientation discrimination thresholds for target grating patches in the presence of vertical 'distractor' patches, for two separate tasks. On separate sessions observers were required to judge the orientation of the target (relative to vertical), or to identify its location on the screen. The performance of both tasks depended on set-size, but in a different way. Orientation thresholds for the location task increased only slightly with set-size, with a power-law dependence (log–log slope) of about 0.2, consistent with the increase in uncertainty. Thresholds for orientation discrimination showed a much stronger dependence on set-size, with log–log slopes of 0.5 (square-root relationship), consistent with the action of second-stage integration. For both tasks, the slopes remained invariant with added visual noise of up to 50% contrast. Further evidence for second-stage integration for the discrimination but not for the location task was provided by manipulating the orientation of the distractors: tilt in the direction of the target aided orientation discrimination but hindered location judgments, while tilt in the opposite direction had the reverse effect on both tasks. The results suggest that discrimination invokes a second-stage integrator that is modifiable by attention, while location is achieved by local independent mechanisms.

◆ **Visual search for modally and amodally completed regions**

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An object may often appear complete even when partially occluded by an overlapping region (amodal completion), or when camouflaged on a similar background (modal completion). In the latter case, illusory contours may be perceived and the completed region may appear transparent. Recent studies suggest that completion phenomena have a preattentive locus in perceptual processing and occur in the absence of focal attention and regardless of specific task demands. There have been few clear attempts, however, to directly compare the contribution made by modal and amodal completion processes to preattentive processing. In the present research we use the visual search paradigm to test whether the illusory phenomena associated with modal completion function effectively as preattentive cues. If they do, then a modally completed target should pop out of a field of amodally completed or perceptually incomplete distractors. No such pop-out effect should be found, on the other hand, if modal and amodal completion both follow an identical processing path in preattentive vision. In addition, manipulations such as figure/ground contrast reversal, known to selectively affect the strength of modal completion, should modulate any pop-out effect associated with modal completion. Preliminary data suggest that modally and amodally completed regions have diverging representations at the level of preattentive vision.

◆ **Form coherence: a measure of extrastriate pattern processing**
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We have proposed (Braddick et al, 1997 *NeuroReport* **8** 1919–1922) that 'form coherence thresholds' measure global processing by pattern-sensitive mechanisms in the ventral cortical stream. Within a display of randomly oriented line segments, a region of variable coherence contains a proportion of segments aligned tangentially to concentric circles. We have measured coherence thresholds for such patterns as a function of region radius, and compared them with similar thresholds for regions of parallel texture. In both cases log threshold decreases linearly with log radius up to a critical radius, typically 10–13 deg for concentric patterns and 3–7 deg for parallel texture. We conclude that concentric forms are detected by larger receptive fields at a higher level in the visual pathway. fMRI measurements reveal brain areas which are differentially activated by patterns containing a coherent concentric form versus random line segments. These include regions in: lateral occipital gyrus; a more posterior occipital focus; fusiform gyrus; and posterior intraparietal sulcus. These regions are interdigitated with, but appear not to overlap, the areas differentially activated by motion coherence. Thus form coherence appears to tap a network of extra-striate areas specialised for pattern processing, but not necessarily anatomically ventral in the brain.
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PERCEPTUAL ORGANISATION

◆ **Neural circuits for perceptual grouping**
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How does the laminar architecture of visual cortex generate perceptual groupings that maintain sensitivity to the contrasts and spatial organisation of scenic cues? A model of local circuits in V1 and V2 can choose which groupings cohere and survive, even while balanced excitatory and inhibitory interactions preserve contrast-sensitive measures of local boundary likelihood. Mechanisms of long-range monosynaptic excitation and short-range disynaptic inhibition support inward perceptual grouping between two or more boundary inducers (interpolation), but not outward grouping from a single inducer (extrapolation), even though excitation is mediated by (outward) axonal projections among model pyramidal cells. Model V1 cells also attentionally prime LGN cells, using a top–down, centre–surround network, which suppresses LGN cells that do not receive positive feedback, while selecting, enhancing, and synchronising activity of those that do. No previous model has resolved the paradox concerning how (necessarily nonlinear) decision circuits in a feedback architecture (for context-sensitivity) can display continuously graded responses, whereby stronger inputs (such as illusory-contour inducers with greater support ratio) lead to proportionately stronger outputs (such as illusory-contour clarity). The model simulates psychophysical and neurophysiological data about perceptual grouping, including illusory-contour formation and Gestalt grouping laws.

◆ **Perceptual organisation of Gabor lattices: Relations between Gestalt principles of grouping-by-proximity and grouping-by-similarity**
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Dot lattices are perceptually organised in parallel strips of dots in the direction of the shortest vector in the lattice. The strength of this grouping is an exponential decaying function of the relative distances between the dots (Kubovy et al, 1998 *Cognitive Psychology* **35** 71–98). To investigate how grouping-by-proximity is modulated by other grouping principles like similarity, dots were replaced by Gabor patches whose local orientation corresponded to one of the three shortest distances in the lattice. Observers were asked to indicate the global orientation of the perceived strips in these Gabor lattices and response frequencies were subjected to linear-regression analysis. The slopes and intercepts of the regression functions were affected by the local orientation-alignment conditions. Results indicate that grouping-by-proximity can be modulated by other grouping principles like orientation similarity. When both principles are congruent, the

perceived orientation is very stable. When orientation alignment is in a direction of a longer vector, organisation along this direction will become more likely than based on distance alone. Neural-network simulations will be developed on the basis of what we know about cooperation and competition between local orientation-tuned units in the early layers of the visual cortex.

◆ **Transformational apparent motion in the volume domain**
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Prior to analyses using transformational apparent motion it was thought that form cues play little if any role in determining the perceived direction of apparent motion. Transformational apparent motion established, however, that there is not only perceptual 'structure-from-motion' but also 'motion-from-structure.' In particular, certain scenes must be segmented into overlapping objects before motion can be perceived to have taken place over those objects. Thus there is a parsing problem that logically precedes the traditional correspondence-matching problem. In the past I have shown how this segmentation takes place over flat figures that transform their shape. Here I show that segmentation takes place over volumes. In particular, when a 3-D form has been specified in the first frame of a two-frame apparent-motion display, the motion that is perceived upon presentation of the second frame is consistent with the 3-D form specified in the first frame, even when the form appearing in the second frame can be seen to have multiple 3-D interpretations. Thus parsing does not take place in each image independently of how previous images were segmented. Parsing must be understood as a 3-D spatiotemporal process that subsumes both the spatial parsing problem and the temporal correspondence-matching problem.

◆ **The role of depth and $1/f$ dynamics in resolving perceptual ambiguity**
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When confronted with an ambiguous image, such as the Necker cube, viewers experience a spontaneously changing percept. We assess the dynamics of how the human visual system resolves perceptual ambiguity in stimuli that offer multiple interpretations. Three sets of subjects observed the Necker cube for brief, moderate, and extended viewing conditions during which they pressed a key each time they perceived a change in orientation of the cube. Manipulations of binocular disparity served as a parameter to control perceptual stability. Low depth conditions yielded more perceptual reversals than intermediate and high depth conditions. Linear and nonlinear time series analyses were performed on time intervals between reversals. Fourier analyses performed on time series of reversals show $1/f$ (pink noise) was predominant in high depth conditions and white noise was present in low depth conditions. These results together with contemporary theoretical models of complex systems (Bak et al, 1987 *Physical Review Letters* **59** 381–384; Los Rios and Zhang, 1999 *Physical Review Letters* **82** 472–475) suggest that depth information may guide our perceptual system into a self-organised state allowing us to resolve ambiguous information.

NATURAL SCENES AND OBJECTS

◆ **Perceived speed of urban traffic**
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We frequently observe moving vehicles, and yet little is known about our ability to judge the speed at which these vehicles are travelling. We investigated speed estimation by observers viewing real urban traffic from an indoor location which largely eliminated nonvisual cues. Ten observers were asked to estimate the speed of a total of 400 vehicles. A video record of the scene permitted the actual speed of each vehicle to be computed by measuring the distance travelled between successive frames. The accuracy of the system was checked by including vehicles travelling at known speeds, whose speedometers had been calibrated. The video record also permitted us to estimate the size, distance, lightness, hue, and saturation of each vehicle. Speed estimates (in miles per hour) were compared with true speed by multilevel analysis. There was a significant underestimation of speed ($\sim$10%), and within this there was a significant effect of the size of the vehicle. The largest underestimation was for the most common size category (saloon cars), with a tendency for both larger vehicles (buses and trucks) and smaller vehicles (motorbikes) to be judged as moving more quickly. There were no significant effects of distance or colour. The implications of these findings are discussed.

◆ **Perception of the illumination of a natural scene by man and machine**
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Changes in illumination conditions can have a drastic effect on the appearance of a scene. These effects are both global across the whole scene and local in the neighbourhood of shadow boundaries. We focus here on the global problem of inferring the illumination direction from both psychological and computational standpoints. In a 2AFC experiment, observers had to decide whether a natural scene was illuminated from the left or the right. Original grey-scale images were intermixed with images combined with a luminance ramp from left to right. Observers were faster and more accurate when the luminance ramp was consistent with the light direction in the original image, and the converse when it was inconsistent. These results indicate that the low spatial-frequency content of an image is critical for the perception of the illumination direction. We then looked at a simple model that could extract the illumination direction from natural images. The model exploits the ON and OFF signals at the level of the retinal ganglion cells for very low spatial frequencies; the 2-D cross-correlation between these two signals provides an estimate of the illumination direction. The model's behaviour is compared with human performance, and its biological plausibility is discussed.

◆ **Local and global coherence in natural images**
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Morrone and Burr (1988 *Proceedings of the Royal Society B* **235** 221 – 224) have shown that aperiodic image features (lines, bars, contours, etc) are congruent in local phase; they are, in effect, locally coherent. Global coherence measures may also be obtained by analysing the relative-phase structure of entire images (this involves computing the Fourier transform of their *n*th-order correlation functions), and natural images appear to display certain consistent properties in this respect. For example, after whitening (to remove the effects of power-spectral structure), images are generally positively kurtosed, and this kurtosis appears to stem mainly from higher spatial frequencies (Thomson, 1999 *Journal of the Optical Society of America A* **16** 1549 – 1553). Higher-order statistical techniques were used to investigate the relationship between local coherence and global coherence in natural images. It was found that many of the observed constraints on the relative-phase structure of natural images can be explained by assuming that they are finite, discrete samples of a visual environment that contains randomly positioned aperiodic features. Thus, fundamentally local phenomena appear to place constraints on the global higher-order structure of natural images, and human visual processing may be matched to these constraints.

◆ **Categorisation of complex natural images in extreme peripheral vision**
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Humans are very good at detecting animals in briefly flashed photographs of natural scenes, both in central [Thorpe et al, 1996 *Nature (London)* **381** 520 – 522)] and in parafoveal vision [Fabre-Thorpe et al, 1998, in *Computational Neuroscience: Trends in Research* Eds J Bower (New York: Plenum Press) pp 7 – 12]. To test how far this ability extends into the periphery, we tested, ten human subjects in a 180 deg panoramic viewing theatre. 1400 highly varied photographs (37.5 deg high by 25 deg wide) were flashed for 28 ms, and subjects were asked to release a button if the image included an animal. Image position varied randomly from trial to trial with nine possible positions covering the entire horizontal extent of the visual field. Performance was remarkably good and decreased linearly with eccentricity from 93.3% for central presentations, to 60.4% for images centred at 75 deg, a remarkable result given the very low ganglion cell densities so far in the periphery. Note that this level of performance was only possible if the subjects were made to guess—most subjects were totally unaware of what had been presented in the far periphery. The results imply that rapid, automatic, and largely unconscious processing may be far more sophisticated that has been thought in the past.

◆ **Counting features**

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It has been widely assumed that we see objects by means of features. But what constitutes a feature? There hasn't been any way to even tell how *many* features an object has. Probability summation models have long assumed that we detect objects by independently detecting their features. But they don't say how many features there are in the object. This has not mattered for modeling of detection, but is crucial when considering identification, which may require detecting several features. Feature counts are presented from two new techniques; one is based on the finding that efficiency is inversely proportional to the number of features in the object (Pelli et al, 1999 *Vision Research* in press), the other is based on a theoretical result about how psychometric function shape depends on the number of features (Pelli, 1985 *Journal of the Optical Society of America A* **2** 1508–1532). These two techniques, requiring only the measurement of identification threshold in noise, or frequency of seeing curves at several contrasts, provide the first counts of features in familiar objects.

◆ **The 'patchwork engine' II: Possible applications of local symmetry in early vision**

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The 'patchwork engine' (van Tonder and Ejima, 1998 *Perception* **27** Supplement, 33) segments images into 'patches' based on local symmetries (medial axes) of shape. Local symmetry is traditionally associated with higher-level shape description, but we need to reconsider its relevance in early vision, after Lee et al (1998 *Vision Research* **38** 2429–2454) showed V1 simple cell responses are also related to medial axes. Segmentation of natural images is first presented to illustrate recent progress in model development. The model finds meaningful subparts of global shapes. Merging of subparts leads to more global image features if smoothness of resultant outlines of merged patches is constrained. Applying the patchwork engine to texton textures locally segments the space between textons. We show that local comparison of segments reflects global texture boundaries. This offers an elegant tool to explain segmentation asymmetry and differential sensitivity to different textons in human texton perception. We further demonstrate that binocular fusion of either a random-dot stereogram (RDS) or the local symmetries of that RDS image leads to a similar 3-D percept. Local symmetry information is more compact than the RDS image itself and may have profound implications for a model of binocular fusion. We interpret this again in terms of comparison and merging of image segments. Our conclusion is that two primitive tasks, comparison and merging of segmented image parts, hold the key to understanding the role of local symmetry in low-level vision.

MONDAY and TUESDAY

POSTERS A

COLOUR, LIGHTNESS, AND BRIGHTNESS

◆ **Do chromatic sensitivity thresholds reveal red–green dominance in grating-detection tasks?**

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We have tested the influence of colour vision mechanisms in chromatic-grating detection thresholds. The stimuli were isoluminant red–green (r/g) or blue–yellow (b/y) sine-wave gratings generated on a CRT colour monitor. Chromatic contrast values were selected along the r/g axis (deutan line) or y/b axis (tritan line) according to Boynton's model; in addition, two intermediate axes were selected by adding the same r/g and y/b contrast values. Along each axis, we measured the threshold contrast for sixteen spatial frequencies from 1.0 to 4.0 cycles deg^{-1}. Each threshold was the mean of two measurements obtained with a three-interleaved 2AFC staircase procedure. The test stimulus appeared in one of two time intervals and the other interval was blank. On one hand, the results showed a significant increase of b/y sensitivity for both intermediate axes. This apparently indicates a strong dominance of the r/g mechanism over this range of spatial conditions. On the other hand, the results derived from r/g sensitivity were also in agreement with the aforementioned r/g dominance. For one of the observers, this dominance seemed to be so strong that the addition of some amount of b/y contrast to the r/g contrast did not modify the r/g sensitivity threshold.

◆ **Depth reversal of Mach's book and lightness constancy**

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To provide an explanation of the depth reversal observed in the monocular viewing of an asymmetrically illuminated folded white card, Mach [1886 *Beiträge zur Analyse der Empfindungen* (Jena: Fischer)] suggested a systematic interaction between lightness sensation and depth perception. Here, the meaning of Mach's implication is investigated, not by natural depth reversal, but by a simulation of these phenomena on two stereograms in which the perceptual lightness of each plane, illuminated or shadowed, in correct or in reversed perspective, is measured. The stereograms are of two types (convex or concave), produced by turning Mach's book sideways. In the convex condition (correct depth), the perceptual lightness of the upper light-grey surface seen illuminated is judged as being darker than the real lightness, and that of the lower dark-grey surface seen shadowed, is judged as being lighter. However, in the concave condition (reverse depth), the upper surface which must be shadowed appears lighter, and the lower surface which must be illuminated, appears darker. The foregoing results support Gilchrist's notion that the perceptual lightness of each surface of an illuminated object is determined by the clues of perceptual depth. However, these results cannot be explained by his coplanar contrast effect principle.

◆ **Measurement of colour discrimination ellipses for surface colour with texture**

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Most experimental studies on colour discrimination were performed with uniform colours. Techniques employed in such studies may not generalise to actual surface colours of industrial products. We propose a new technique to measure colour discrimination ellipses for textured surfaces, such as plastic, leather, and fabric. In our experiments, visual stimuli were produced by mixing two appearances by means of a beam splitter (half-silvered mirror): the surface colour of an actual object and the non-object colour on a CRT display. Using a computer-controlled system, the experimenter changed the colour appearance while preserving the texture appearance. Every stimulus was perceived as the surface of a coloured object. We prepared reference and test stimuli by this technique and obtained colour discrimination ellipses by the method of limits. We examined automotive plastic parts with a grained leather pattern. Results were interpreted according to a colorimetric system we developed for colour quality control.

◆ **'Transmode' in colour appearance and change in blackness of colour stimuli under various luminance conditions**

A004

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We studied the mode of appearance of coloured test patches T on a grey surround S as a function of the estimated amounts of colourfulness C, whiteness W, and blackness B. Five well-trained subjects watched stimuli on a CRT screen and evaluated M, the degree of surface vs film colour appearance on a 5-step scale, and the relative amounts of the three colour components ($C + W + B = 100$). The total number of stimuli was 108: 3T hues × 2T luminances × 2T sizes × 3T saturations × 3S luminances. The surface colour appearance increased as the $L(\mathrm{T}) : L(\mathrm{S})$ luminance ratio decreased, corresponding to the brightness decrement of T (Uchikawa et al, 1989 *Perception* **18** 83–91; Whipple et al, 1988 *Perception & Psychophysics* **43** 367–372). This effect was stronger for red than for blue and green patches. No significant effect of size was found. A multiple regression analysis suggested that the mode of colour appearance M depends on blackness B ($r^2 = 0.53$) more than on colourfulness C ($r^2 = 0.23$) and whiteness W ($r^2 = 0.03$).

◆ **Effect of visual sensitivity change on colour constancy**

A005

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Previous studies have shown that human colour constancy and chromatic adaptation to illuminant are incomplete. We investigated relationships between incomplete colour constancy and incomplete chromatic adaptation. We performed an asymmetric colour-matching experiment by using a small room with a variable chromaticity illuminant on the ceiling. The matching stimulus was a CRT screen, placed behind a 3 deg × 3 deg hole. A test colour chip was presented in another smaller room of different illuminant through an 8 deg × 15 deg window. Observers were asked to match just the colour appearance between these two stimuli, and to make unique-white settings under each illuminant. Illuminants of both rooms were varied independently from white (D65) to blue, orange, green, or purple. The matching results showed incomplete colour constancy, and unique-white results showed incomplete chromatic adaptation. On applying a simple gain change to cone responses, to align unique-white, the colour-matching results also coincided across illuminant conditions. This may imply that the shift in visual sensitivities to colour appearance is related to an incomplete state of chromatic adaptation. However, the gain was not the same as that implied by the results of flicker photometry measured at the same time. We would suggest that some classes of visual sensitivity change affect colour constancy, and others do not.

◆ **The effect of luminance gradients on lightness constancy**

A006

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The term lightness constancy describes the ability of the visual system to perceive surface colour correctly despite changes in the level of illumination. It has been shown that smooth luminance changes are strong cues of changes in the level of illumination. In the present work, we simulated a classical-lightness-constancy-type display on a CRT monitor (Bruno, 1994 *Vision Research* **17** 2205–2214) where a smooth luminance gradient was presented at the border dividing the lower from the higher luminances side of the display. Observers had to perform a matching task in a within-subject design: 3 luminance ratios (30 : 1, 10 : 1, 2 : 1) × 4 conditions, ie gradient throughout the whole display dividing border ('congruent' condition), gradient throughout the inner background dividing border only (first 'incongruent' condition), gradient throughout the outer background dividing border only (second 'incongruent' condition), and no gradient (control condition). For all the tested ratios and compared to the control condition, we found that congruent condition holds better lightness constancy, while the two incongruent conditions show only little failures of constancy. Congruent condition increases lightness constancy. However, since the loss of constancy in the incongruent conditions is modest, it seems that the visual system considers smooth luminance gradients as an important source of information on illumination changes, even when edge cues are partially incongruent.

◆ **Colour constancy and the AMBEGUJAS phenomenon**

A007 S S Bergström, K-A Gustafsson, T Jakobsson (Department of Applied Psychology, University of Umeå, SE 901 87 Umeå, Sweden; e-mail: sten-sture.bergstrom@apsy.umu.se)

The present study addresses the definitions of colour constancy in the AMBEGUJAS, a phenomenon described by Jakobsson et al (1997 *Perception* **26** 531–541). A flat display having three vertical grey stripes is presented in two coloured illuminations, one at its top half and another one at its bottom half. Perceptually the display appears reversible: it spontaneously shifts between two different folded 3-D alternatives (A and B). Alternative A consists of different surface colours under two diffferent coloured illuminations, whereas alternative B consists of a uniform grey partly under a coloured illumination and partly under a shadow. The AMBEGUJAS phenomenon can also appear on displays made from coloured paper and in white light. In the present experiment we have used a series of 3-stripe displays made from coloured paper in white light. The central stripes have either constant lightness but varied hue, or constant hue but varied lightness. The poster shows the stimuli as well as the experimental data. The distinction between colour constancy and Koffka's notion of unit formation is briefly discussed.

◆ **Accuracy in heterochromatic luminance matching**

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The accuracy of making a heterochromatic luminance match for different colour pairs was measured. This was done by the minimum-motion technique, as introduced by Anstis and Cavanagh [1983, in *Colour Vision* Eds J D Mollon, L T Sharpe (London: Macmillan) pp 155–166]. The minimum-motion technique was chosen because the direction of motion is related to the sign of luminance contrast (under isoluminance the direction is ambiguous). Such a sign is needed for matching with adaptive methods—eg when using the MUEST method (Snoeren and Puts, 1997 *Journal of Mathematical Psychology* **41** 431–439) as done here. The MUEST method not only estimates the horizontal offset of a psychometric curve, but also its steepness, which is a measure of accuracy. For different colour pairs, the proportion of motion seen to the right was measured as a function of luminance contrast. As expected, accuracy decreases with colour difference. However, accuracy results for colours in the yellow area are surprising. First, the accuracy is minimal when matching the luminance of yellow with itself as compared to all other homochromatic colour pairs. Second, the accuracy of making the luminance match between a colour in the yellow area and another colour increases with increasing colour distance.

◆ **AMLA: A quick psychophysical method to measure CRT achromatic contrast without sophisticated instrumentation**

A009 I Vitini, J Lillo, J Collado¶, A Caballero (Departamento de Psicologìa Diferencial y del Trabajo, Universidad Complutense de Madrid, Campus de Somosaguas, Facultad de Psicologìa, Pozuelo, E 28223 Madrid, Spain; ¶ División de Diseño y Creación de Contenidos, Telefónica I+D c/Emilio Vargas 6, E 28043 Madrid, Spain; fax: +34 91 394 3189; e-mail: psdify2@sis.ucm.es)

Sixteen trichromats and a dichromat evaluated two versions of a method (AMLA) designed to measure CRT achromatic contrast using only a standard luxometer. AMLA is based on the following facts: (i) There is no difference in computing contrast from standard or relative luminance. (ii) Photographic luxometers can be fixed to the CRT screen to give accurate measurements of relative luminance with achromatic but not chromatic, stimuli. (iii) A psychophysical task was developed to determinate which achromatic stimuli have relative luminance similar to a specific chromatic stimulus. The psychophysical task uses the differences in spatial sensitivity between chromatic and achromatic stimuli and requires one to change (version 1; successive) or to select (version 2; simultaneous) the achromatic background such as to make it more difficult to read a message written with the colour whose relative luminance we want to know. Both versions gave similar, and excellent, accuracy. The simultaneous task required less time and received a better subjective evaluation (measured by the semantic differential technique). When a protanope used the AMLA his adjustment selections were significantly different from the controls and similar to those predicted from the Smith–Pokorny cone fundamentals (darker grays for stimuli rich in long wavelengths; lighter grays for the reverse).

◆ **Temporal integration of blue-on-yellow luminance increments and decrements in human vision**

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S-cones and their associated pathways have longer integration time than other cone systems. We studied temporal integration for blue-light increments and decrements to investigate how the

S-cone system summates over time signals of opposite sign generated by the same receptor pool. S-cone isolation was achieved by presenting stimuli against a background consisting of 3 cd m^{-2} blue light and 300 cd m^{-2} yellow light. The stimuli were luminance increments and decrements of the blue light over a circular area, 4 deg in diameter. They were presented at 12.5 deg eccentricity. At brief durations the decrement thresholds were similar to the increment thresholds, but were lower at durations longer than 100 ms. The time of complete integration was longer for decrements than for increments, contrary to the expectations from time-integrative properties of the chromatic opponent system. Controls with red-on-red stimuli showed shorter integration time, independent of the stimulus sign. The extended temporal integration for decrements cannot be a property of the S-cones, but possibly reflects differences in post-receptoral ON and OFF mechanisms receiving S-cone input.

◆ **Macular dichromats chromatic space: basic categories and partial asymmetries**

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Two protanopes and two deuteranopes (diagnosed by the Nagel anomaloscope) and four controls used the eleven basic colour terms to name the 1795 tiles of the Natural Colour System with either 2 deg or 8 deg stimuli. We then derived the volumes corresponding to each basic category for the two groups and the confusions among categories. For both stimulus sizes, the dichromats, particularly the protanopes, made many naming errors, such as excessive use of pink and distortions of the lightness ranges of basic categories. However, fewer errors were made, particularly for large stimuli, than predicted by using the standard dichromatic isochromaticity lines. It appears that dichromats can compensate for the missing foveal cones, in part, by effective use of lightness information. In addition, performance is consistent with the conjecture that information from peripheral cones substituted for that from the missing foveal cones. These results were used to develop a model of dichromats colour naming which was tested against the data from two earlier experiments in which different stimuli to the NCS have been used. The model predicts naming errors well, and can account for why asymmetries occur between categories that tend to be confused. For example, dichromats name purples blue more often than the other way round.

◆ **Colour affects motion**

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A small disk which moved linearly was presented on a computer display (standard stimulus). This separated in the centre of the display into two disks, whose lightness and chromaticness could be varied (test stimuli). One target moved towards the left and the other towards the right. The observers judged in which direction the original stimulus appeared to have moved. Judgments were affected by two target features; lightness and chromaticness. When the original stimulus and one of the target stimuli have the same colour (experiment 1), the judged direction of motion depends on whether the colour of the test targets is or is not the same as the colour of the original stimulus. When the original and the test stimuli had different colours (experiment 2), the judgments were found to depend on target lightness when the background of the motion targets was dark, and on their chromaticness when the background was light. Since the background affected perception of target colour only by simultaneous contrast, and the retinal inputs were not changed, the data suggest that judgments of motion direction may depend upon colour perception which results from processing of retinal inputs, and not upon retinal inputs directly.

◆ **Colour signal constraints for the perception of transparency**

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The perception of transparency is an example where the visual system can correctly interpret changes in colour signals in terms of physical properties of surfaces (D'Zmura et al, 1997 *Perception* **26** 471–492). We investigated the nature of the constraints on colour signals imposed by transparency and argue that the notion of the invariance of cone-excitation ratios (Foster and Nascimento, 1994 *Proceedings of the Royal Society of London B* **257** 115–121) as a possible basis for perceptual colour constancy may also be used to define the stimulus conditions necessary for perception of transparency. We computed the cone-excitation ratios for 1000 pairs of

Munsell surfaces viewed under D65 directly and through achromatic and chromatic (Gaussian profiles) filters with a Monte Carlo simulation. Cone-excitation ratios were found to be approximately invariant for filters with broad-band (bandwidth $s > 20$ nm) transmission spectra but only weakly invariant for filters with narrow-band transmission spectra. Psychophysical experiments were conducted with simulated Munsell surfaces and chromatic filters with varying transmission spectra (controlled by s). The strength of the transparency percept was found to be correlated with s and with the invariance of the computed cone-excitation ratios. The invariance of cone-excitation ratios is a possible (though not necessarily unique) cue for the perception of transparency.

◆ **Discrimination games for colour categorisation**

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We describe an artificial-intelligence experiment with visually grounded robotic agents which discriminate and categorise colours. The experiments are part of a larger experiment in bootstrapping cognition and language by groups of autonomous distributed agents. The architecture of the agents consists of a perception module, a categorisation module, and a lexicalisation module. Colour categories are obtained by using sensory channels based on human physiology and psychophysics and by presenting real-world physical environments that humans frequently encounter. In the colour experiments, we use as sensory channels two opponent chromatic channels, one lightness channel and one saturation channel. With experiments on pictures of natural scenes the following trends emerge, which show interesting parallels with the development of human colour categories: (i) The lightness channel is the most frequently used; the next is the red/green channel, then the yellow/blue, and finally the saturation; (ii) there is hardly any subcategorisation, which is almost always in the lightness channel; (iii) regarding combined categories, the chromatic channels combined with the lightness channel are more widely used than chromatic/chromatic combinations.

◆ **Orientation selectivity of opponent-colour channels**

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In human colour vision, it is generally accepted that signals from the three types of receptors (L, M, S) are combined in two opponent-colour components and one achromatic component. Here we are concerned with the cardinal directions A, Cr1, and Cr2 defined by Krauskopf (1982 *Vision Research* **22** 1123–1131). Selectivity for orientation is among the clearest properties of striate cortical cells. We chose to measure it using gratings defined by variations along Cr1 and Cr2 chromatic dimensions at isoluminance. We used the technique of simultaneous masking to investigate orientation selectivity. Stimuli were defined by Gabor functions on one chromatic component (Cr1 or Cr2), and we added a masking sinusoidal signal on the same component with a larger spatial extension. For various orientations of the stimuli, we measured the detection threshold with a constant masking signal. Our results suggest similar orientation selectivity of luminance and chromatic components in the range of spatial frequencies tested. These results have been successfully used in a sub-band decomposition for the design of an optimal perceptual image-coding scheme. They are also used to explain contrast dependences between components.

◆ **Colour saturation constancy: effects of illuminant changes**

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Colour saturation constancy is defined as the independence of perceived object colour saturation from the illuminant. We report experiments designed to investigate how changes in illuminant affect the colour appearance of surfaces. The computer-generated stimulus pattern consisted of an array of 117 colour samples (Munsell chips with chroma 2, 4, and 6 at value 7) on a black surface. The test sample in the middle of the array had achromatic coordinates and the mean of the colour coordinates of all samples was also achromatic. We simulated 10 different illuminants with coordinates located on the locus of Munsell chips under illuminant C with chroma 6 and value 7. The task for the subject was to set the test sample to achromatic under different illuminants. The change from chromatic to achromatic is equivalent to a saturation change for samples whose colour is complementary to the illuminant colour. If the change of the sample coordinates is small, saturation constancy for such a sample is poor. The data showed relatively poor colour saturation constancy for illuminant changes near the red–green axis compared to illuminant changes near the blue–yellow axis.

◆ **Scoring efficiency on the Farnsworth–Munsell 100-Hue test after brain damage**

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The new computerised Farnsworth–Munsell 100-Hue test programs have been used for testing colour discrimination of brain-damaged patients and healthy controls (Malone et al, 1977 *Perceptual and Motor Skills* **44** 1249–1250). The type and the degree of colour deficit has also been computed by measuring the zones of colour confusion. We examined 48 persons with frontal, temporal, and occipital lobe damages of epileptic origin (loci of damage confirmed by EEG, CT, and MRI data) as well as 48 healthy controls. All persons examined were 20 to 45 years old. Visual acuity functions in both groups were normal. A total error score between 20 and 100 was taken as the range of normal competence for discrimination. Patients with temporal lobe damage performed worst in colour discrimination (mean score 157), whereas patients with frontal and occipital lobe damage showed less impairment (means 110 and 135, respectively). Error scores of healthy controls were consistent with normal colour discrimination (mean 52). The pattern of colour impairment was identified by bipolarity, a clustering of maximum errors in two regions which were nearly opposite. No correlation between colour defectiveness and locus of brain damage has been found.

◆ **Displacement colour constancy versus illuminant colour constancy**

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Displacement colour constancy refers to the invariance of perceived surface colour under changes in surface position with possible simultaneous changes in illuminant. If displacement colour constancy depends on the invariance of perceived colour relations between adjacent surfaces, it should be poorer than simple illuminant colour constancy. An experiment was performed in which observers binocularly viewed CRT computer simulations of two illuminated Mondrian patterns consisting of 49 (7×7) abutting 1 deg $\times$ 1 deg square surfaces each drawn at random from the Munsell set. The two patterns, each subtending 7 deg $\times$ 7 deg when viewed at 100 cm, were independently illuminated by daylights of 6700 K and 25 000 K. The central and one other 1 deg $\times$ 1 deg square surface in one pattern were interchanged in the other pattern, where they were illuminated by an independent illuminant, which the observer adjusted so that the two patterns appeared to comprise the same surfaces but evenly illuminated by different lights. Patterns were presented continuously. The extent of the colour constancy was quantified by Brunswick-like ratios. These ratios were found to be similar to or slightly less than the values obtained when there was no interchange of surfaces. Displacement colour constancy may depend on perceived colour relations over widely separated regions in an image.

◆ **Detection and localisation of lightness changes under simultaneous illumination changes**

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To study sensitivity to the reflectance change of one surface in a pattern undergoing a simultaneous illumination change, Plet and Gerbino [1999 *Investigative Ophthalmology & Visual Science* **40**(4) S749] used chromatic displays in which item numerosity and colour ratio numerosity were dissociated. We ran two experiments using the same paradigm to investigate performance in the achromatic domain. After a short exposure under one illuminant, the display underwent a change simulating an increase of illumination intensity. In half of the trials, a simultaneous lightness change affected one item. In experiment 1, human sensitivity to simulated lightness changes under a simultaneous intensity illumination change was measured by using a detection task. In experiment 2, a localisation task was used to investigate whether the identification of the position of lightness change involves an additional cost. In both experiments the pattern of results was the same as in the chromatic experiment of the previous study. When the number of items is kept constant, detection and localisation performances improve as the number of background lightness ratios increases. When the number of lightness ratios is kept constant, performance deteriorates at larger item numerosities. A flat performance function is obtained when the negative effect of item numerosity compensates the positive effect of lightness ratio information. We found no evidence of an additive cost of localisation relative to detection. When a lightness change is detected, its localisation is accurately perceived.

◆ **Colour constancy in the primate outer retina: A simulation study**

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Using NeuronC, a simulation language developed by R Smith, University of Pennsylvania, we built a computer model of a central part of the outer retina. The model contains 140 cones, 7 H1 horizontal cells, 5 H2 horizontal cells, and several sign-converting as well as sign-conserving bipolars. Distribution of cones and chemical synapses of different signs are similar to those that can be found in the primate retina. Horizontal cells of the same type are electrically coupled. There are no electrical synapses between horizontal cells of different types. Cones are presynaptic to horizontal cells and get inhibitory feedback from the same cells. The receptive field area of the different cells is modulated by the amount of electric coupling of the horizontal cells. Stimulating the retina with lights of different wavelengths over the visible spectrum produces monophasic hyperpolarisations in the horizontal cells similar to those that have been found by recordings in the monkey retina. In the simulation, physiological correlates of the red–green opponency can be found in bipolars of the L-cones and M-cones, correlates of the blue–yellow opponency in the S-cone bipolars. By variation of retinal illumination in two stimulus fields, horizontal cell coupling, and efficiency of feedback onto cones we examined the conditions under which colour constancy can be found in the cone and bipolar signals.

◆ **A linear model of the reconstruction of surface appearance under changes of illumination**

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Spectral properties of reflected light depend on the compound product of the spectral radiant power distribution of the light source and the surface reflectance function. A linear model for recalculating the tristimulus values of a reflected light under a new illumination with respect to reference illuminant was developed. Decomposition of the compound product is achieved by using the first three eigenvectors of Munsell colours for reconstructing the surface reflectance function and imitating an illuminant with a broad-band spectral radiant power. A square matrix of the linear transformation operator depends on the illumination changes. The eigenvectors of the transformation matrix are assumed as hypothetical channels and it is shown that, in general, simple von-Kries-type scaling of their sensitivity functions is an inadequate method for perfect colour constancy. Performance of the computational algorithm was tested on a set of Munsell chips. Tristimulus values of Munsell chips under illuminant C ($x = 0.3101$, $y = 0.3162$) were taken from the Munsell Renotation System (Newall et al, 1943 *Journal of the Optical Society of America* **33** 385–418) as input data. Output data were calculated for changes to illuminant A ($x = 0.4476$, $y = 0.4075$) and illuminant S ($x = 0.2319$, $y = 0.2318$), and compared with experimentally obtained data (Kelly et al, 1943 *Journal of the Optical Society of America* **33** 355–375). No significant difference between theoretical and experimental data was found.

◆ **No effect of high illuminance on colour naming by dichromats**

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Deuteranopes have just two types of cone in the macula, and have reduced discrimination along the red–green axis relative to normal trichromats. The short-wavelength cone does not provide a usable signal in response to medium and long wavelengths, but, at very high illuminances, the signals can become suprathreshold. McMahon and MacLeod (1998, *Vision Research* **38** 973–983) showed that under high-illuminance viewing, discrimination by dichromats was enhanced, consistent with a functional short-wavelength signal. Here we tested three deuteranopes and two controls, under low (2500 lux) and high (20 000 lux) illuminances with either small (1.8 deg) or large (5 deg) stimuli, using a colour-naming task. Deuteranopes made more naming errors than normals under all conditions, particularly for small visual fields. However, neither the kind of error, nor the number of errors, changed under the high-illuminant condition. We conclude that whatever gain there may be from suprathreshold short-wavelength signals, it is not sufficient to change naming and categorisation, at least in deuteranopes.

◆ **Discrimination ellipses of deuteranomalous observers plotted in personalised colour diagrams**

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Comb-filtered spectra are sinusoidally modulated spectral power distributions defined by their spectroradiometric characteristic and independent of prior colorimetric calibrations. At constant levels of modulation, when phase varies from 0° to 360°, the chromaticity coordinates of comb-frequencies describe ellipses. These ellipses vary in size and orientation with the comb-frequency. But, for a given observer, discrimination thresholds for two different comb-frequencies ought to be represented by the same elliptical contour in a chromaticity diagram, provided that diagram is based on the correct fundamentals. We estimate the spectral position of the M-cone fundamental of Stockman et al (1993 *Journal of the Optical Society of America* **10** 2491) that minimised the difference between the two best-fitted discrimination ellipses determined for four deuteranomalous observers. When the spectral position of the M-cone fundamental was determined, discrimination ellipses of all observers were elongated vertically. The sizes of the ellipses of two deuteranomalous observers were comparable to those of normal observers, but two times larger for the other two. This result suggests that there is a factor hindering colour discrimination in some anomalous dichromats in addition to the expected loss from the proximity of their M-cone and L-cone fundamentals.

◆ **Optimal quantisation of colour image**

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As for all coding methods, two features determine the performance: the first one is the representation space and the second is the quantiser. Our aim has been to obtain a perfectly decoded image without degradation at a low compression rate. We have determined a perceptual colour space and different interactions between the components of this space. The colour space is composed of one achromatic component and two chromatic components: a 'red–green' axis and a 'blue–yellow' axis. The study of interactions has shown two interesting features: a pedestal effect and a masking effect. These two effects could be integrated into a coding scheme in order to determine the information used by the human visual system. These features should improve the quality of decoded images without decreasing the compression rate. The second part presents a colour-image coding scheme based on the features of the human visual system. We have used our colour space and introduced the major interactions. The perceptual colour space, perceptual quantisation laws, and a set of interactions is used in a subband-coding scheme. The use of such a space and of the interactions brought about a high compression rate without visible impairments.

◆ **Photoreception as a semiconductor-optoelectronic process**

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Research on the photoconductivity of the retina is being conducted by measuring volt–ampere and lux–ampere properties, spectral, kinetic, optical, and temperature characteristics. Two components of photocurrent were investigated (long-range and short-range). We discovered an electrooptical effect in the retina as well as its connection with rhodopsin. This finding supports the hypothesis that the primary vision processes have a photosemiconductor nature. It is therefore suggested that the information coming from the retina is not only of bioelectrical but also of optical nature.

◆ **On continuity perception in brightness change**

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The perception of continuity in brightness changes, obtained with discontinuous stimuli, is analysed by the method of experimental phenomenology. The results show that uniformity in the evolution can be obtained also with discontinuous steps of luminance. Obviously, the perception of continuity depends on the difference in luminance between successive steps and on the duration of the steps. Quite unexpectedly, the passage from continuity to discontinuity perception is not at all simple: the inspected object first shows a continuity in brightness change, then exhibits various kind of flickering and internal pulsations, and eventually changes its brightness by successive fits and starts. Several other phenomena are encountered: for instance, short sequences ranging over extreme luminances show only three or two visible phases. Moreover, the continuous changes of brightness give a marked perception of 'velocity'; starting with the deep black and going to the shining white, observers first notice stillness, then a movement that begins slowly and attains a

maximum of velocity at an intermediate brightness, then a slowing down at high brightnesses, and eventually stillness again, near the maximum brightness.

◆ **Luminance adaptation level and processing time**

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Choice reaction time as well as simple reaction time decay as a hyperbolic function of luminance (Piéron's function). Additionally, it has been shown that, when luminance approaches threshold, the exponent of Piéron's function increases drastically. Such a change has led us to suggest that relative and not absolute luminance determines processing time. This was confirmed by the results of experiments in which background luminance was varied. The results suggest that reaction times (RTs) depend primarily on luminance discriminability, which combines the effects of contrast and luminance adaptation level (LAL) of the visual system. Here, we tested directly the effect of the LAL on RTs. Subjects had to decide if a luminous rectangle (5 levels of luminance were tested) was oriented ±45° from the vertical. In order to vary the LAL without changing the luminance contrast, a luminous ring (5 levels of luminance) surrounded the target. Mean RTs did not vary with the luminance of the ring, but an interaction between target and ring luminance was found. This result suggests that Piéron's function depends on the LAL of the visual system, at least for low target-luminance levels.

◆ **A new effect of space brightness enhancement**

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A new effect of spatial brightness enhancement is presented. The illusion is based on the observations of the artwork of the 17th-century French painter Georges de La Tour. Though the painter himself did not show the effect in his masterpieces, the author derived the possibility of such an illusion directly from de La Tour's work. The effect is the brightness enhancement of a low-luminance homogeneous field achieved with shape from shading inducers. The effect is discussed in relation to Ehrenstein's cross, Varin and van Tuijl's neon spreading effect, Musatti's assimilation displays, Kanizsa's triangle, Kanizsa's anomalous transparency effect, and Zavagno's glare and black-hole effects. A parametric study is also presented where the strength of the effect is measured.

◆ **Terminal brightness perception in continuous brightness change**

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Let us consider a 3 deg dark-grey disc that gradually (1, 2, 3 s) grows in brightness till it reaches the brightness level of the background (48.9 cd m^{-2}, and other 6 levels: 47.3, 45.6, 43.9, 42.4, 40.8, 39.3 cd m^{-2}). This is mode A. Let us consider also a 3 deg light-grey disc that in the same time decreases in brightness till it reaches the above mentioned level of the background and other 6 levels: 50.7, 52.5, 54.2, 56.1, 57.9, 59.8 cd m^{-2}. This is mode B. The problem is which is the last level of brightness perceived by the observer. Fifty-two subjects indicated that level in a row of 8 comparison stimuli, for 84 trials. Results show that the chosen comparison stimulus is roughly the same, irrespective of the mode (disk lightening, disk darkening), the time of the evolution (1, 2, 3 s), and, above all, of the actual level of luminance at which the evolution of the stimulus stops (the level of the background and the other six levels). This unexpected result lacks a simple explanation, and other experiments are being carried out in order to outline the limits of the phenomenon.

◆ **Achromatic compositions**

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Many achromatic colour phenomena, such as simultaneous contrast, involve relatively simple visual displays. However, in recent years many authors have constructed more complex compositions which challenge traditional theories in novel ways. I present several sets of variations of such compositions, involving different types of transformations of the original displays, which may help to disentangle the factors that affect achromatic colour perception. One set of compositions is based on Adelson's argyle illusion, and shows its relation to simultaneous contrast. Another set of demonstrations involves variations on a strong new illusion by Logvinenko. A third set presents examples of Metelli-type and non-Metelli-type transparency phenomena. Finally, a fourth set involves compositions that show neon-colour, shape-from-gradients, Zavagno's endazzlement effect, and bistability. The latter two sets also demonstrate how a simple change of the luminance of the background can have strong effects on the perceptual organisation of the figures.

◆ **When blurred is better than sharp**

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When observers view a red–green sinusoid they often report that it looks more like a square wave. The visual system seems to 'deblur' the chromatic input, similar to motion sharpening reported by Burr [1980 *Nature (London)* **284** 164–165]. We presented observers with square-wave gratings modulated either along isoluminant red–green, yellow–blue, or luminance directions. The observers' task was to judge which of the two gratings, the standard (fixed external blur) or the comparison (variable amount of blur), looked sharper. Blur difference thresholds for red–green and luminance directions are very similar and as low as 0.5 to 1 min of arc; for yellow–blue blur thresholds are higher by a factor of 3 to 6. When we plot blur thresholds as a function of the external blur (ranging from 0 to 2.5 min of arc) we find a 'dipper function' with the lowest blur threshold for all colour directions at about 1 min of arc of external blur, in accordance with findings by Watt and Morgan (1983 *Vision Research* **23** 1457–1477) for luminance edges. We conclude that the luminance and red–green channels have similar spatial properties, whereas the yellow–blue channel exhibits a poorer blur resolution. Furthermore, the location of the minimum blur thresholds suggests that the internal blur for the luminance and red–green channel is identical.

◆ **An investigation of a prior exposure effect in lightness**

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When observers look into a room in which the walls are completely patterned with dark-grey to black rectilinear patches (stimulus 1), they see the highest luminance target, actually dark-grey, as white. If the same room has real whites added (stimulus 2), the same dark-grey surface is seen as mid-grey. However, when stimulus 2 is immediately preceded by stimulus 1, observers initially see the dark-grey target in stimulus 2 as a white that slowly darkens to mid-grey. We investigated this strong temporal effect. (a) We compared two matching tasks. Observers either made matches from immediate memory or memorised the Munsell scale and made matches inside the room. (b) Using a between-subjects design, we obtained matches at different delays from 3 to 120 s. (c) We inserted either a period of complete darkness or a different scene (our lab) between stimuli. We found (i) no difference between the matching tasks, (ii) that the temporal effect diminishes over our test interval but does not disappear completely, and (iii) a greater weakening of the temporal effect by the darkness. We interpret our results in terms of interacting temporal frameworks.

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◆ **Legibility in achromatic and chromatic car instrumentation**

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To create an innovative automotive dashboard, we evaluated different foreground/background colour combinations. Two achromatic (black/white and white/black) and two chromatic (amber/green and green/amber) dashboards were tested. Twenty participants performed a primary task (tracking of a moving target) and a secondary (matching) task. If the primary task was correctly executed, the secondary-task target (a speed-limit sign) was displayed. Observers judged if the speed indicated on a simulated dashboard was higher or lower. Reaction times and errors were measured. Performance was better in terms of accuracy with a superiority of increment (white/black) over same-contrast decrement (black/white) dashboards. Among decrements, the chromatic amber/green solution was better than the achromatic black/white. Among increments, the white/black solution was always the best.

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◆ **Application of a computational model of brightness perception in patients with cerebral lesions**

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Since the 1960s the spatial contrast sensitivity (CSF) has been connected with spatial-frequency channels and analysed by the Fourier transform theory. Recently, some have proposed theories that postulate a nonlinear transformation of signals in the visual cortex to explain certain

brightness phenomena. Within this second approach, Pessoa et al (1995 *Vision Research* **35** 2201 – 2223) developed a network model to explain brightness data involving sine-wave gratings. Employing this network in a previous study, we were able to simulate the responses of patients with cerebral lesions who suffered from a loss at high frequencies. Here, we analyse two new facts: (i) how an increase in the number of implemented scales modifies the network output, and (ii) the contribution that this approach renders to the analysis of cortical pathologies. The results reflect the abnormal long-range spatial interactions at a cortical level described by neurophysiology, and demonstrate that this abnormality also produces a loss of sensitivity at high frequencies, which has previously been considered to be the result of cut-off frequencies of linear mechanisms. This approach could provide a response to Bodis-Wollner's earlier question (1972 *Science* **178** 769): Why should the high-frequency channels of the visual system be more vulnerable to cerebral lesions?

COMPARATIVE ASPECTS OF VISUAL PERCEPTION AND HEMISPHERIC DIFFERENCES

◆ **Estimation of size and distance of moving targets in frogs and toads**

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In frogs and toads prey-catching or escape responses, when faced with an approaching object, are triggered depending on the size of the object. Parameters affecting size estimation of three-dimensional moving objects were investigated in these species, taking into account the visual characteristics of the stimuli (differently coloured spheres with a diameter varying from 0.25 to 5 cm) and of the environment. Spheres at different distances were moved against differently textured backgrounds in front of the subjects. Both adequate responses (ie escaping when faced with a large object or trying to catch a small one) and inadequate responses (ie escaping in front of a prey-size object or trying to catch a very large one) were analysed. Responses in the various situations showed that in frogs and toads object size and distance estimation are affected by the same parameters as in humans: the texture of the background, correlation between angular size and speed of the approaching object, its contrast and colour, and spatial position.

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◆ **Pigeons classify human faces by attending to their surface properties**

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Converging evidence suggests that the way in which pigeons sort complex sets of visual stimuli into experimenter-defined categories does not require conceptual abilities. The pigeons' behaviour can instead be described with much simpler lines of analysis, such as learning to attend to the relevant feature dimensions. In a recent experiment, pigeons classified visually complex images (male and female human faces) by means of their global properties, which covaried with the semantic content of the categories. Using a correspondence-based representation of faces, we found that pigeons preferred to exploit the surface properties of faces to their spatial properties (Troje et al, 1999 *Vision Research* **39** 353 – 366). Furthermore, by reducing the informational content of the images in steps, we investigated if pigeons are able to track the task by subsequently attending to those features that most nearly divide the stimulus space into the experimenter-defined categories. The features used can be readily described within the framework of correspondence-based representations. We measured the pigeons' spontaneous classification of synthetic images that were created to vary only on one of the first three principal component axes and found an extremely orderly relationship between the pigeons' respondings and the position of the stimulus in face space.

◆ **Perception of orientation: A lesion study in monkeys**

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In order to study the role of areas V6/V6a in orientation perception, we trained an adult female *Cercopithecus aetiops* to detect the angle of a grating generated on a PC monitor and to signal its orientation (clockwise vs counterclockwise) by touching corresponding light spots on the same touch screen. After the training period, the monkey underwent two restricted cortical lesions, first in the anterior bank of the parieto-occipital sulcus of the left hemisphere, and, after two months, in the corresponding region of the right hemisphere. Post-mortem examination

showed that, in both hemispheres, V6a was almost completely removed, while V6 was only partially affected. The tests, repeated after each lesion, demonstrated that damage to the V6 complex compromised orientation detection more seriously after the right-hemisphere lesion. Two explanations are offered for this finding. The right hemisphere had taken over the function lost after the lesion of the left hemisphere and, consequently, the function was completely lost after the second lesion. Alternatively, orientation detection is a strongly lateralised function and a lesion of the left hemisphere really does not interfere with it. Experiments are in progress to validate these observations in more animals.

◆ **Hemispheric differences in the image repetition effect**

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Image classification was performed on the basis of the large-axis position (1 : 1.5) of images. The images were randomly presented in the left (LVF) or the right (RVF) visual fields. The percentage of correct classification and ERP of O1, O2, P3, P4, TPO1, TPO2, F3, and F4 were studied for 'same' and 'different' images. It was found that in the LVF 'different' images were purely classified in comparison to 'same' images. In the case of RVF stimulation the correctness of classification did not depend on the previous image. Differences in ERP to 'same' and 'different' images were revealed both in LVF and in RVF. The earliest differences of 'same' and 'different' images were observed in the contralateral hemisphere 50–90 ms after stimulation. In the time interval 130–270 ms differences between 'same' and 'different' ERPs were more expressed in the right hemisphere (P4, TPO2, O2) and were not connected with the side of stimulation. In the frontal area of both hemispheres, differences between 'same' and 'different' ERPs were observed only during RVF stimulation.

◆ **A possible interhemispheric asymmetry of sustained and transient channels in vision**

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It is well known that there are two independent channels in the human visual system: the transient one and the sustained one. In this work we tested the hypothesis that the representation of these channels in the left and right hemispheres of the human brain is asymmetric. We developed experimental computer methods based on the visual masking effect. As stimuli we used four target letters, which were exposed for a short time in the right or in the left visual field. When stimulus was turned off, a bilateral mask appeared with some time delay (stimulus onset asynchrony, SOA). The mask was presented at the location of the target letter as a cross embedded in a ring. To obtain a maximal masking effect, SOA was varied in the range 10 to 200 ms for each subject. The subject's task was to recognise the target letter. The results showed that for each subject the maximal masking effect occurred at a different SOA for target stimulus in the left and in the right visual fields. We conclude that there is an asymmetry between transient and sustained channels.

◆ **Ecology and vision: comparative analysis of detour behaviour in Mediterranean Herring Gull (*Larus cachinnans*) and other steppe-living birds and passeriformes**

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Detour behaviour is the ability to avoid an obstacle present between the animal and its goal. It is manifested the first time when the animal has to solve the test; while after the task, the performance is conditioned by the experience and the animal performs better (detour learning). Koehler first proposed it as a test for insight learning. It has been demonstrated in several species of mammals and in some families of birds (corvids, parrots, and chickens). Motivational factors and perceptual factors (related to the perceived 'barrier character') strongly affect the bird's performance. In this work some of the factors that influence detour behaviour and detour learning in a number of species of birds (herring gull, steppe-living birds, other passeriformes) have been examined, with special reference to the perceptual characteristics of the obstacle (barrier). Different kinds of barriers were used to test the animals (transparent glass screen), horizontal bar, vertical bar, grid bar (obtained by superimposing the vertical bar on the horizontal bar). The results suggest a difficulty in negotiating transparent barriers, and species differences in dealing with vertically and horizontally elongated barriers. The results are discussed along with those reported by other authors to evaluate from comparative and evolutionist points of view the perceptual abilities of species of birds in different ecological niches.

◆ **Dissociation of spatial orienting between left and right hemispheres**

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Attentional modulation of cortical hemispheres was tested by manipulating visual fields and responses. Target (rectangle) was presented at two different locations within the left or the right visual field. Reaction time (RT) was measured for detection of the target with the left or the right (i) hand or (ii) foot. Subjects ($N = 4$) were all right-handed. Location repetition revealed longer RTs in the left visual field with the left hand ($-54 + -8$ ms, 'inhibition of return') or the left foot ($-44 + -14$ ms). Similar inhibition occurred with the right hand ($-34 + -12$ ms) and the right foot ($-24 + -13$ ms). When target appeared in the right visual field, RTs became shorter (facilitation) with the right hand ($+56 + -18$ ms) or foot ($+41 + -14$ ms). Facilitation disappeared with the left hand or foot. This is the first demonstration of the foot response showing common tendencies of detection to the hand response. The results suggest a functional dissociation between two cortical hemispheres: an inhibitory-orienting process generated in the right cortex, whereas a facilitatatory process originated from the left cortex. The facilitation is analogous the one in fine positional-discrimination (Tanaka and Shimojo, 1996 *Vision Research* **36** 2125–2140) or letter identification (Terry et al, 1994 *Perception & Psychophysics* **55** 279–286), suggesting a location-scrutinising process in the left cortex.

◆ **Right and left hemisphere modes of analysis**

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In the chick there is preferential use of right or right ear at first encounter with a visual imprinting object or sound. Once the chick is attached, this preference shifts to left ear or eye. The association of early learning with left-hemisphere processing is further shown by age-dependent bias to left-hemisphere control on days when imprinting is likely to occur in natural broods (eg day 3 and day 5). It is argued that left-hemisphere control goes with persistent response to selected cues (which in the case of imprinting will include motivating cues). Similar focused attention, with right-eye use, occurs in feeding in both chick and zebra fish, leaving the left eye available for other tasks.

LEARNING, MEMORY, AND DEVELOPMENT

◆ **Playing the Motion Game improves reading rate but not as a consequence of greater contrast sensitivity**

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We reported that dyslexic subjects who play the Motion Game increase sensitivity for discriminating direction of motion and increase reading rate (1999 *Investigative Ophthalmology & Visual Science* **40** S33). Are these changes correlated? Half of our dyslexic subjects played the Motion Game 1–2 times per week, each session lasting 5–10 min, enough time for ten direction thresholds, each threshold requiring 20–30 trials of an achromatic, coarse (0.25–4 cycles deg^{-1}), low-contrast sine-wave grating that moved left or right. The other half of our subjects played a visual search (Control) game for the same amount of time. Starting in early summer and continuing into fall, Motion (but not Control) subjects increased their contrast sensitivity, $\sim$5% per session. By contrast, during the summer, when subjects were not reading, Motion (and Control) subjects did not increase their reading rate. In the fall, when subjects were in school, Motion (but not Control) subjects did increase their reading rate (average 104% versus 8%). Over all subjects, improvements in reading were not correlated with improvements in contrast sensitivity. We conclude that: (i) playing the Motion Game did improve contrast sensitivity; (ii) the Motion Game was effective in helping dyslexic subjects learn to read; (iii) improvements in contrast sensitivity and in reading rate were dissociated.

◆ **Transfer effects in ratings of visual velocity**

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In a scale-transfer study, we examined how ratings of velocity depend on the presentation order and frequency of stimuli. Subjects judged each of 5 stimulus velocities using three categories (slow, moderate and fast). A pre-shift set of stimulus velocities for one group served as a post-shift set for the other. In experiment 1, stimulus orders were contingent on frequency skews of the sets:

mainly frequent (slow or fast velocities) occurred on the initial trials. The data indicated an incomplete scale-transfer effect. In contrast to the pre-shift run, the post-shift ratings of the two groups coincided. In experiment 2, order of presentation and frequency skews were contrasted: mainly infrequent (slow or fast velocities) were presented earlier. Similar ratings obtained in the pre-shift and post-shift runs suggested a reciprocal adjustment of the subjects' scale to stimulus order and frequency. In accordance with earlier work (Sokolov et al, 1999 *Perception & Psychophysics* forthcoming), our findings indicate that across runs the judgment scales are sensitive to contextual frequency and presentation order. Experience with remote initial velocities and the overall frequency of distinct velocities jointly affect estimation of the actual speeds. The data are simulated with the aid of the judgment option model by Baird [1997 *Sensation and Judgement: Complementarity Theory of Psychophysics* (Mahwah, NJ: Lawrence Erlbaum Associates)].

◆ **Learning higher-order statistics of simple shape sequences**

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We examined what type of sequential information humans extract from a series of simple shapes. Twelve shapes were arranged into four 3-element mini-sequences (triplets). During training, subjects viewed a random, continuous sequence of these triplets, with each shape in the sequence presented for 1 s. During testing, subjects viewed two shape triplets in a 2AFC task and had to decide which had been embedded in the sequence during the training phase. When element frequency [P(a)] was held constant but the frequency of shape triplets [P(a,b,c)] was not, subjects correctly identified the higher-frequency shape triplets (69%, $p < 0.005$). When element frequency varied so that the frequency of shape triplets or pairs was held constant but the transitional probabilities between elements [p(B|A)] were different, subjects correctly identified not only the more frequent single elements (72%, $p < 0.001$), but also the pairs or triplets with higher transitional probabilities between the constituent elements (61.2% and 60%, both $p < 0.05$). These results suggest that subjects can extract higher-order statistical information of dynamical scenes such as joint probabilities, and that this extraction can be based on conditional probabilities even when the frequency of occurrence of elements and the joint probability of triplets is an unreliable statistical source for prediction.

◆ **Effects of additional information on performance for acquiring cognitive map through exploration of virtual environment with egocentric view**

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Although devices such as road maps and car-navigation systems are available, our primary information for wayfinding is cognitive maps—internal representations of the environment. Given that an allocentric cognitive map is learned through egocentric views of an explored environment, a transformation from an observer-centred to a world-centred frame of reference is necessary. We simulated wayfinding in a real-world environment by a virtual-reality maze. We investigated the effects of information added to the egocentric views during exploration on the acquisition of cognitive maps. Performance was evaluated by measuring the accuracy of learned cognitive maps and of estimates of distance and direction between particular objects. Results demonstrated that adding landmarks on the maze produced a significant improvement in accuracy of the acquired maps as well as shorter learning times. In addition, when information about heading direction was presented with the egocentric views, performance was better than when no additional information was presented. These results suggest that transformations from an observer-centred to a world-centred frame of reference benefits from information about observer orientation besides the temporal change in the egocentric views.

◆ **Spatial-frequency interactions in the human visual system at the resolution limit: practice effects**

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We carried out psychophysical experiments to measure masking functions for rectangular gratings at the resolution limit and to study practice effects. Distractors were four rectangular gratings having the same or higher spatial frequencies. The observer's task was to discriminate the orientation of the test grating. Distances between the test central gratings and the distractors varied from $\frac{1}{2}$ period to 10 periods of the test-grating frequency. Two sets of experiments differed in the layout of the distractor: fixed or random orientations of surrounding gratings. In each experimental set, at least 150 presentations of each stimulus were accumulated on different experimental

days. At the beginning of the experiments we measured standard masking functions; we found that observers' performance deteriorated for small separations. Sizes of the inhibitory areas were about 2–3 periods of the test frequency. At the end of 3–4 experimental sets, the size of the inhibitory areas decreased and became so small that it could be explained by the optical point-spread function. The order of sets (fixed vs random orientation of distractors) was an important factor in the training course. The results obtained are different from perceptual learning effects reported for detection tasks.
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◆ **Vision function in old age and its change over time**

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Information about general vision function in old age is lacking—particularly beyond the age of 75 years. We assessed vision in 900 people aged 58–102 years (median 75 years), measuring spatial and temporal resolution and sensitivity, adaptation, glare, stereopsis, colour discrimination, and visual and attentional fields. Though standard acuity is well maintained even into very old age, other measures show substantial decline in the same individuals. A single aging function fits data of all spatial measures well. Stereoacuity is not well maintained. 60% of 90-year-olds cannot detect 340 s of arc disparity. Much of the decline in stereopsis is attributable to subtle retinal defects (rather than altered cortical binocular processes), even with apparently good vision. Though standard field size does not change much with age, in many elders fields shrink to zero given a moderate attentional load. To date 291 individuals have been retested (mean intertest interval 4 years) providing the first such longitudinal data on vision of the aged. The agreement between longitudinal and cross-sectional data is excellent for many measures, but there are large discrepancies for a few, most notably low luminance acuity (larger change longitudinally), contrast sensitivity, and acuity in glare (smaller change longitudinally), perhaps reflecting cataract removal between tests.

◆ **Effects of background luminance on representational momentum for lightness**

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Two experiments were performed to examine memory for target lightness. In experiment 1, a series of three targets that increased or decreased in luminance were presented in the same location against a white or black background. Observers judged whether the lightness of a probe was the same as the lightness of the third target (or differed). Memory was displaced backward (eg towards an average of previous target luminances) when targets were presented against (i) a black background while luminance increased, or (ii) a white background while luminance decreased. In experiment 2, a series of three targets implied translation rightward; targets increased or decreased in luminance and were presented against a white or black background. Observers judged whether the lightness of a probe was more or less bright than the lightness of the third target. Memory was displaced backward as in experiment 1. Backward displacements in memory for target lightness in experiments 1 and 2 were consistent with findings by Brehaut and Tipper (1996 *Journal of Experimental Psychology: Human Perception and Performance* **22** 480–501), but inconsistent with predictions of a forward displacement (ie representational momentum) by Freyd (1987 *Psychological Review* **94** 427–438).

◆ **Gollin test on noisy backgrounds**

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We studied recognition of contour images made of Gollin test in children aged 3–6 years in the presence of additive white noise. We measured the minimal percentage of contour filling needed to recognise an image. Children were tested four times on four different days. The two sets were extracted from the same eight objects with the use of different random contour elements. The order of image presentation with and without noise differed in the two sets, which were shown to different children. We found higher percentages of contour filling by children in the presence of noise in both sets. In the first set, the critical arbitrary level of 10% contour length was recorded on the 3rd day for images without noise, but was never reached in the presence of noise. In the second set, this level was recorded on the 2nd day for images without noise, and on the 4th day in the presence of noise.

A smaller contour-filling percentage was needed to recognise images after learning in the course of experiments. A significant correlation between contour-filling percentage and age was found only in the second set. This correlation became weaker with learning.

◆ **Exploring perception in humans inhabiting simple virtual environments**

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We report the results of a comparative study of problem-solving behaviour in humans inhabiting simple virtual environments, alternating between auditory, visual, and mixed stimuli. Virtual environment comprises a 2-D grid where each node is associated with a 'percept' consisting of a beep of a certain pitch and/or a coloured square appearing on the screen. Using four buttons, subjects could move through this environment, hearing the beeps (and/or seeing the coloured squares) one at a time as they visited the nodes. Subjects were told that they should produce the goal percept by using as few as possible button presses. Subjects were unaware of the environment setup. Subjects improved their performance with experience in terms of decreasing number of button-presses. To account for this, we hypothesised the emergence of internal structures that (i) embrace the history of agent–environment interactions during the task, and (ii) modify the agent's future perception of stimuli from that environment. After solving the above problem, subjects were asked to classify time sequences of percepts according to their feeling of how 'good' or 'bad' the sequence was as a 'description' of the route to the goal. Results are discussed with respect to different modalities (audio/visual/mixed) of the stimuli.

◆ **Practice and transfer effects in the detection of embedded figures**

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In earlier studies, we found practice effects in the detection of embedded figures. In the present experiment, we studied whether practice effects would transfer to new items. Stimuli were 168 pairs of whole and part figures. Half of them were positive, the other half negative items (ie the part was actually embedded in the whole or not, respectively). The experiment consisted of three sessions. In session 1, 56 items were presented. Session 2 contained these and 56 new items. In session 3, the 112 items from earlier sessions and again 56 new items were presented. The items were shown on a monitor. Subjects were asked to decide whether or not the part was embedded in the whole and to respond by pressing one of two buttons. Response latencies and error rates were recorded. We found a beneficial effect of practice: items stemming from session 1 were answered faster and with fewer errors in later sessions. Furthermore, a transfer effect appeared: the solution of new items in sessions 2 and 3 was facilitated compared with the results of session 1. These findings show that the improvement of performance in the detection of embedded figures may not be attributed to an effect of memory alone.

◆ **Visual object learning as a function of polysensory prior knowledge**

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We have investigated, within the context of a supervised learning paradigm, how various forms of prior knowledge and the availability of depth cues influence learning speed and recognition performance of previously unfamiliar objects. Prior knowledge was varied in terms of sensory modality (visual versus haptic versus visuohaptic). The degree of depth information was modified by comparing stereoscopic versus nonstereoscopic viewing conditions. Learning speed was defined as the number of training cycles necessary to reach a given criterion concerning the classification of a fixed learning set of two-dimensional (2-D) views of the test objects. Recognition was measured as generalisation performance with respect to a set of novel 2-D views of the same objects. There was a significant effect of sensory modality on both learning rate and recognition performance. In particular, a short prior haptic exploration proved to be much more effective than enhanced depth information during learning. The results emphasise the role of polysensory information in the ontogenesis of visual representations of 3-D objects. The implications for theories of human object recognition and related computational models are discussed.

◆ **Memory for angular velocity: a psychophysical study**

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We measured the accuracy with which observers can retain the representation of the angular velocity of an object after it disappears. A dot moved along a 8 deg diameter circle (always displayed) with an angular velocity w. At $t = 750$ ms the dot disappeared and, after a variable time interval Δt (500, 1250, or 1850 ms), a tag was displayed perpendicular to the trajectory. Observers fixated on the centre of the circle and reported whether the disappeared dot was ahead of or behind the tag. The observers' uncertainty in the dot position was measured via an adaptive staircase procedure. w varied from 0.65 to 2.29 rad s^{-1}. Data from two observers show that, for a fixed Δt, the uncertainty on the angular position of the disappeared dot increases linearly with w. The slopes of the lines increase with Δt. The accuracy of the inference of the dot position is proportional to the amount of information collected by the visual system while the dot is visible. A neural integrator model that accounts for the data is presented.

◆ **Inhibitory zone size, crowding, and visual acuity in children**

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Two sets of psychophysical experiments were carried out and more than one hundred children aged 3–9 years were tested. Test stimulus was a Landolt C in four orientations. Observers were asked to indicate the orientation of each stimulus. In experiment 1, we measured the sizes of isolated Landolt C corresponding to 75% correct. In experiment 2, performance was measured when the Landolt C was surrounded by 4 bars placed at different separations. Children's performance improved with increasing age for both isolated and 'crowded' stimuli. The threshold sizes of the isolated Landolt Cs decreased with age up to 7 years. The sizes of inhibitory areas measured in the 'crowded' task were equal to about 1.75 the sizes of the stimulus at the age of 3–4 years and became the same as for adults and equal to the size of the stimulus at the age of 8–9 years. No significant correlation was found between the sizes of a 'threshold' stimulus and that of the inhibitory areas. We suggest that our results reflect the time-course of visual acuity and development of the crowding effect in ontogenesis.

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◆ **Positional uncertainty and children's single word reading**

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Cornelissen et al (1998 *Vision Research* **48** 471–482) suggested that impaired magnocellular (M) functioning increases the positional uncertainty (PU) and this diminishes reading ability. The aim of this experiment was to replicate a correlation between M functioning (coherent motion) and reading. Secondly, we studied the correlation between positional uncertainty and reading ability. Fourteen children (mean age 8 years 2 months) participated in this study. The coherent-motion task was similar to the task used by Cornelissen et al (1998). In the positional-uncertainty task two fixed blobs were presented at the same height, separated by 14 deg. A third blob (centre blob) was placed above an imaginary line connecting the fixed blobs. The task was to decide to which of the two blobs the centre blob was closest. The psychometric curve was estimated as a function of the distance between the centre blob and the midpoint. PU was defined as the steepness of this psychometric curve. Reading ability was assessed both with a standardised test of words and with non-words. A significant correlation was found both between coherent motion and reading, and between positional uncertainty and reading. These findings corroborate the hypothesis that reading is reduced by higher PU caused by impaired M functioning.

◆ **Cognitive development in normal and visually disabled children**

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More than 1100 infants aged 3–15 months were tested: 900 children formed the normal group, and about 200 children showing small defects in binocular fixation, visual field, or visual acuity constituted the risk group. The age norms were established for such operations as prediction of movement, search for a hidden object, discrimination and memorising of object form, size,

colour, and spatial position. 6–7-month-old infants show prediction of direct movement. They can memorise object size and show amazement when seeing unexpected size change, but this reaction decreases at 9–10 months. At the same time, the surprise reactions to changes of the form of an object increase. We consider these results as evidence of form perception invariant to size. The discrimination of red/green colours develops a little later than that of blue/yellow, by 11–12 months. The infant during the first year of life can estimate and memorise position only in relation to himself (egocentric strategy). The notions about the visual world develop more slowly in the risk group. Restriction or asymmetry of the visual field and especially diminished visual acuity influence infant cognitive development.
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MOTION INTEGRATION AND MOTION MECHANISMS

◆ **The computation of occlusion for motion perception**

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Computational considerations suggest that occlusion is critical to motion interpretation, and an extensive body of psychophysics has demonstrated that human motion perception is affected by occlusion 'cues'. Little is known, however, about how these cues are used to compute the estimates of occlusion that presumably affect motion perception. Here we used the perceptual coherence of an occluded square (Lorenceau and Shiffrar, 1992 *Vision Research* **32** 263–273) to characterise how border ownership and amodal completion are computed from form cues. We manipulated junctions in different locations of the stimulus which might plausibly contribute to occlusion estimates, and used the square's coherence as an index of the visual system's estimate of the probability of occlusion. We found large effects of nonlocal occlusion cues (those which do not abut the square's contours), suggesting that border computations are not limited to the junctions formed at the 'terminators' of moving contours. Border ownership computations also do not appear to be limited to T-junctions; L-junctions can have strong effects. We also found large nonlocal effects on amodal completion—in addition to contour relatability, amodal completion needs room. Together, our experiments suggest a significant role for global occlusion computations in motion perception.

◆ **Motion integration for tracking eye movements: the fast and the slow of it**

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The perceived direction of motion of a sinusoidal grating viewed through an elongated aperture is biased towards the long axis of the aperture. This 'barber-pole' illusion is a consequence of integrating ambiguous 1-D and nonambiguous 2-D local motion signals (line-endings) over the visual field. We probed the temporal dynamics of such motion integration by recording, using a scleral search coil, tracking eye movements driven by large (> 50 deg^2) horizontal or vertical moving gratings (0.3 cycle deg^{-1}, 10 Hz) seen through a diagonal rectangular aperture. The initiation of ocular following responses is first driven at ultrashort latencies (80 ms) by 1-D motion signals, and 2-D motion signals start biasing the tracking direction only 15–20 ms later. Such latency shift is not changed when an elongated foveal mask is superimposed at the centre of the stimulus. The response magnitude in the bias direction is dependent upon the aperture aspect ratio and dramatically reduced by either reducing the contrast of line-endings or indenting the aperture. These results support current models, suggesting that feedforward processing of 1-D and 2-D motion signals have different temporal dynamics, but converge onto a single stage very early in the visual motion stream.

◆ **Overestimation of apparent speed reveals dynamics of long-range lateral interactions**

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Recent studies have suggested that 'association fields' are involved in spatial aspects of contour liking. However, little is known about their temporal properties. We examined the spatiotemporal characteristics of these association fields using an apparent-speed paradigm and a 2IFC design to compare the apparent speed of motions induced by rapid sequential presentation of oriented Gabor patches or elongated Gaussian blobs. We found that observers overestimate the speed of motion composed of aligned elements as compared to that of nonaligned elements. Further experiments showed that this effect: (i) depends strongly on the similarity between element orientation and

direction of the motion path; (ii) remains for curvilinear apparent motion if Gabor orientation is tangential to the motion trajectory. A computational model was developed to explore the role of lateral connections in this effect. Both the computational and the psychophysical results are consistent with the spatiotemporal characteristics of horizontal connections observed in V1, suggesting that this cortico–cortical connectivity could subserve such a perceptual bias. To account for our psychophysical data we propose a model in which 'dynamic association fields' integrate feed-forward and lateral inputs simultaneously (for appropriate speeds in the 40–96 deg s^{-1} range).

◆ **Locomotor pointing with expanding patterns**

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The purpose of the experiment reported here was to determine to what extent braking behaviour depends on a change in the optical expansion rate (τ) of the projected texture (vertical screen) surrounding a target. We also investigated the role of proprioceptive cues by varying subjects' mean of locomotion. Our device allowed an on-line link between texture size and subjects' linear displacement. Subjects moved actively (natural walking), or passively (motorised armchair driven by a joystick) towards a luminous target which was switched off at the initiation of locomotion. The walkers were instructed to stop when the target position seemed to be reached. The dynamic size of texture elements (circular patterns) surrounding the target varied, and we measured subjects' braking responses. As we expected, the target position was underestimated or overestimated in relation to visual expansion-rate conditions. Collisions with the projection screen were expected in a nullified τ-information condition. This was particularly the case with 'passive' subjects. Time-to-contact values were remarkably constant across expansion-rate conditions. Braking before an obstacle seems to be linked to the use of optical expansion, and to the ability to adopt a 'τ-constant strategy' to initiate braking.

◆ **Sensitivity to average speed depends on spatial layout**

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To gain insight into how speeds are combined in structure-from-motion we performed an experiment in which subjects indicated in which of two stimuli a central dot moved with the average speed of the surrounding dots (the signal stimulus). In the nonsignal stimulus the speed of the central dot was either lower or higher than the average. Thresholds were obtained in two conditions in which the distribution of speeds was the same, but in which the spatial layout was either structured (simulating a rotating plane) or unstructured (simulating a rotating cloud of dots). The task in the structured condition could be interpreted as detecting a deviation from planarity. Subjects were aware of this and feedback was given to ensure that an optimal strategy was used. Thresholds were much higher in the unstructured condition than in the structured condition. Moving the centre dot away from the centre made the signal stimulus nonplanar and the threshold increased to that of the unstructured condition. These results suggests that performance in structure-from-motion is not determined solely by noise on individual speed measurements, but also by the spatial structure of the stimulus.

◆ **Persistence does not influence the perceived location of a flash relative to a moving stimulus**

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Spatial extrapolation and differential latency models have been proposed to explain the apparent offset of a flash relative to a moving stimulus. Another possibility is that the flash appears to persist longer than the moving stimulus. Our experiments show that this differential-persistence model cannot explain the illusory flash-offset phenomenon. A flash was presented near a horizontally translating bar at a random point along the bar trajectory. One video frame after the flash, a mask was presented that covered the flash entirely. Subjects judged whether the flash appeared offset to the left or to the right of the bar. The appearance of the flash signals the moment at which the positions of the moving bar and flash are to be compared. However, longer flash persistence could delay the judgment of its apparent location until the bar has moved away from it. The mask should eliminate this delay and therefore reduce the perceived offset. This was not the case: the magnitude of the illusory flash offset remained unchanged with the addition of the mask. The judgment of the location of a flash relative to a moving stimulus is therefore made at the initial appearance of the flash.

◆ **Contrast dependence of the extent of motion integration**

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The conditions under which local motion signals are integrated or differentiated are not fully understood (Braddick, 1993 *Trends in Neurosciences* **16** 263–268). Integration of motion signals is dependent on the spatial frequency, orientation, spatial layout, and contrast of the stimulus [eg Adelson and Movshon, 1982 *Nature (London)* **300** 523–525; Verghese and Stone, 1997 *Vision Research* **37** 397–406; Ohtani et al, 1998 *Vision Research* **38** 429–438; Takeuchi, 1998 *Vision Research* **38** 3069–3082]. We have investigated the contrast dependence of motion integration using a 2IFC speed-discrimination task. Speed-discrimination thresholds were measured as a function of contrast (5%, 10%, and 20%), interelement distance, and the number of the local motion elements (1, 2, 4, 8, and 16 Gabor patches) that moved at a speed of 1.6 deg s^{-1}. We found that speed-discrimination thresholds decrease with the number of Gabor patches. The minimum thresholds were about 1.4 deg s^{-1} for 5% contrast and 1.2 deg s^{-1} for 10% or 20% contrast. Our data also suggest that the number of Gabor patches at which the threshold is minimum is contrast-dependent.

◆ **A model of speed change identification in successive motion episodes**

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A three-stage model for the identification of speed increment/decrement of successively presented motions is suggested. A distinct stage is proposed between encoding and decision stages. Its development was required to explain: (i) performance deterioration for temporally contiguous, relative to well-separated, motion episodes; (ii) the crucial role of SOA in identification of both contiguous and separate motion episodes (Likova, 1998 *Perception* **27** Supplement, 193). It is suggested that speed processing occurs within a temporal window. For SOAs shorter than the hypothesised temporal window, the two speed representations superpose and accuracy deteriorates as an effect of processes like temporal integration, persistence, reverberatory interactions, and backward masking. The model describes a common mechanism that operates for both contiguous and separate motions, and predicts (a) known psychophysical data, (b) temporal window duration, and (c) conditions for independence of speed processing. The model is discussed in relation to other models of visual motion perception. Further directions for its refinement and experimental testing are proposed.

◆ **The nonvisible persistence of position signals**

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A continuously visible moving object is perceived at a different position than one intermittently visible. The persistence of the position signal of a temporarily hidden object at the last visible position may cause this (Lappe and Krekelberg, 1998 *Perception* **27** 1437–1449). Subjects viewed seven dots on a line rotating around the fixation point [Baldo and Klein, 1995 *Nature (London)* **378** 565–566]. The inner three dots were continuously visible, while the outer dots were intermittently flashed (flash duration: 28 or 112 ms; flash-period: 168 ms). In these circumstances, subjects perceived an angular offset. They were told to cancel this offset by using two buttons that rotated the inner dots. Unknown to the subjects, this changed the time when the inner dots were halted for the remaining duration of a flash period. Subjects reported that this operation allowed them to control perceived relative orientation. Alignment was perceived if the continuous dots stopped when the flashed dots were hidden. On the assumption of equivalence of the internal position signals with perceived alignment, this suggests that the position signal of hidden objects persists at the last visible position. In 2AFC experiments in which all dots were flashed once, but with different durations, we determined that nonvisible persistence lasts approximately 200 ms.

◆ **3-D curvature contrast effect in motion-defined stimuli**

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A 3-D curvature contrast effect has been reported for shape-from-shading stimuli (1994, Curran and Johnston *Perception* **23** Supplement, 16) and for stereo-defined stimuli (1997, te Pas et al *Perception* **26** 1337–1338). We investigated whether such an effect is also found for motion-defined stimuli. Stimuli consisted of a small central part (4 cm radius on the screen) with relatively high

curvature, surrounded by a large outer part (10 cm radius) with lower curvature. The stimuli were covered with random dots and had an angular velocity of 30 deg s^{-1}. Viewing was monocular. Observers were seated 50 cm in front of the monitor. They were presented with two stimuli successively and had to decide which of the two central parts had the highest curvature. The curvatures of the outer parts were varied systematically. The results show a clear 3-D curvature contrast effect: of two identically curved central parts, the one with the smallest outer curvature is perceived as more curved.

◆ **Is motion processing unitary?**

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Conventional psychophysics categorises the motion discrimination space into three tasks: speed detection, speed discrimination, and direction discrimination. But, to an ideal observer, only the speed (or displacement) difference and the noise level matter. Tests were carried out to establish whether human performance in the various motion tasks showed the working of a unitary mechanism or the combined outputs of more than one mechanism. The whole motion discrimination space was examined with random dots that underwent a sudden jump or displacement. The discriminability (d') was measured as a function of the standard and comparison displacements. The ideal observer model and a nonideal observer model which adds internal noise to the stimuli both predict a planar response surface. When the dot motion was noiseless, the planar surface fit well except for much higher than expected sensitivity for speed detection. This suggests the working of a mechanism that uses positional cues. The planar surface also fit well when motion noise was added to the displays, though response surface residuals showed the presence of a speed energy mechanism. It is concluded that unitary (ideal or nonideal observer models) and nonunitary modes of motion processing coexist.

◆ **The accuracy and confidence of movement discrimination**

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We studied how the accuracy of left–right movement direction discriminations is related to the feeling of perceiving. The stimuli were two LEDs. The level of difficulty of the task was manipulated either by varying SOA (0–18 ms, $L = 32$ cd m^{-2}) or intensity (0.6–1.6 cd m^{-2}, SOA = 30 ms). Observers discriminated between movements in two opposite directions. Additionally, they rated their confidence about their discrimination decisions. Results indicated that the level of the independent variable (eg SOA or luminance) predicted observer confidence better than observer discrimination efficiency. A sequential analysis revealed different dynamics of discrimination decisions compared to confidence ratings: response–response autocorrelations were negative for discrimination but positive for confidence. In a control experiment, observers discriminated between left or right spatial positions. Results from the control experiment confirmed that the negative sequential dependence is specific to movement discriminations and is not observed in two-alternative spatial discriminations. We conclude that the processes underlying discriminations and confidence are not the same. Discrimination decisions are only partly based on the phenomenal experience of movement.

◆ **Phenomenal identity in the visual field: the Ternus effect**

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The problem of 'phenomenal identity' was first studied by Ternus in 1926 with apparent motion displays, the best known of which consists of three horizontally arranged spots (a, b, c) exposed at time t_1, followed, at time t_2 by three spots displaced rightwards by one place (b′, c′, d′). Typically, several cycles are flashed in stroboscopic presentations, so that with interstimulus intervals shorter than 40–60 ms the observer perceives the two middle elements as stationary and the outer element jumping back and forth (element motion: EM), while with longer interstimulus intervals the three flashed elements seem to move back and forth as a whole (group motion: GM). We have analysed the Ternus effect varying the number of elements and the distance between them, using only one sequence of the two frames and a long duration of the first. The experimental results indicate that the EM/GM threshold significantly increases as the number of elements and the distance between them increases (as Korte's laws for stroboscopic movements suggest). Since the number of elements does not appear as an independent variable in the current literature, further investigations will be useful for the validation of the persistence or information-integration models of the Ternus effect.

◆ **Suprathreshold auditory motion affects perceived visual motion**

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Sekuler et al [1997 *Nature (London)* **385** 308] demonstrated that the presence of an auditory stimulus influences the perception of ambiguous visual motion. We measured the sensitivity for discriminating motion direction in a random-dot kinematogram (RDK) in the presence of a synchronised suprathreshold auditory motion stimulus, the Franssen stimulus (Hartmann and Rakerd, 1989 *Journal of the Acoustical Society of America* **86** 1366–1373). The sound could either move to the left, to the right, or be static; the visual motion was either leftward or rightward. Psychometric fits reveal that the thresholds for direction discrimination of visual motion are the same (4% motion coherence) for all auditory conditions. The point of subjective equality (PSE), however, is shifted. In the control condition with a stationary auditory stimulus, most subjects show a bias towards choosing the right direction equivalent to 4% coherence. If visual and auditory stimuli move in a consistent direction, the PSE decreases from 4% to 2%. If auditory and visual motion is inconsistent the PSE increases to 6%. In conclusion, our data suggest that an auditory moving sound introduces a response bias, but does not affect the sensitivity in the visual-motion identification task.

◆ **Depth reversal of a random-dot hollow face on a motion-parallax display when its dot density is varied**

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A random-dot hollow face is reversible when it is simulated with a motion-parallax display yoked to lateral head movements (Sakurai and Miyakoshi, 1998 *Perception* **27** Supplement, 115). We investigated whether the depth reversal of the hollow face occurs when its dot density is varied. With low, mid, and high density (20, 50, 80 dots deg^{-1}, respectively) random-dot displays, we simulated four surfaces. Two of them were a convex human face and a concave hollow face. The rest were arrays of circular bumps and dents which had either convexity or concavity in the centre of the pattern. Observers monocularly viewed the display while moving their heads laterally, and reported verbally whether the centre of the pattern looked convex or concave. With a low-density display, all surfaces were perceived correctly as they were simulated. With mid-density and high-density displays, there were significantly fewer correct responses to the hollow face than for any other surface. The depth reversal occurred not with the low-density display but with the mid-density and high-density ones, since the higher the density was, the more face details there were.

◆ **The motion aftereffect caused by adaptation to a moving disk with a drifting grating**

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The interaction between the movement of a global pattern and that of a local component included in the global pattern was studied. The apparent direction of a surrounding disk with a drifting grating is affected by the temporal frequency of the grating, and most affected when a high-contrast grating drifts at 6.4 Hz (Ishihara, 1998 *Perception* **27** Supplement, 192). In this previous experiment, the disk was made to drift horizontally from left to right, and the grating drifted vertically. The disk was seen to move diagonally upwards at 2.5° when the grating was made to drift in an upward direction. In the present experiment, the motion aftereffect (MAE) caused by adaptation to this moving disk with an upward drifting grating was measured. The results showed that MAE direction was down to the left at 26°. It seems that the local movement affected the global movement. However, the effect of local movement was stronger than that observed in the previous experiment. As an explanation, an integration model based on a weighted vector-sum operation is proposed.

◆ **Experimental study of the behaviour of drivers approaching road tunnels**

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Safe and effective road travel depends critically on the direct control of vehicles by the drivers, which in turn is based on their visual efficiency and on their perception of objects and events. Thus, driving skills depend critically on vision and visual perception. By correctly perceiving road layout and condition, a driver can choose the appropriate vehicle speed, select the best

trajectories, and monitor distances from other vehicles. These perceptual processes ultimately result in safe road behaviour. The aim of the present work was to study the behaviour of car users as they approach the entrance of a tunnel. In this situation, if the tunnel walls are too close to the roadway a noticeable reduction in speed and an adjustment of the trajectory of the vehicle towards the centre of the carriageway is observed as the vehicle approaches the entrance. This may be understood in terms of a perceptual model based on monitoring angular retinal speeds. To test this model, we carried out an experimental investigation in different environmental situations derived from the analysis of video images to reconstruct the trajectories of the vehicles and their kinematic characteristics.

◆ **Configurational effect on speed perception**

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The influence of configurational characteristics on the perceived speed of a moving pattern has been investigated. Four different repetitive configurations, each of which was composed of figural elements—vertical, horizontal, oblique, or V-shaped stripes—were used as test patterns. In each test pattern, the width of figural elements was varied in three steps. The speed of the test pattern moving downward was changed in two steps. Five students served as subjects in the experiment. Each subject was asked to make magnitude estimates for perceived speed of the test pattern under a total of 24 conditions (4 patterns × 3 widths × 2 speeds). A three-way analysis of variance revealed that all main effects and their interactions were significant. The horizontal, oblique, and V-shaped patterns were perceived as being much faster than the vertical pattern. Except for the vertical pattern, the patterns with narrower stripes were seen as being faster than those with wider stripes. Most remarkable was that the interaction between pattern and speed effects was significant. Configurational effects were found more clearly when the pattern moved fast than when it moved slowly.

◆ **Effect of spatial configuration on motion integration**

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The effect of spatial configuration on globally coherent motion was examined. Two differently oriented lines were presented in separate apertures and moved horizontally, creating the perception of either a coherent motion in the horizontal direction or two component motions orthogonal to each line. The spatial configuration of the aperture was set to 100%, 50%, or 0% of overlap in the spatial phase of the lines. The overlap of presentation time was 100% (simultaneous), 50% (partial overlap), or 0% (successive presentation). The distance between the apertures was kept constant. The following results were obtained: (i) The percentage of perceived coherent motion increased as a function of temporal, as well as spatial, overlap, with temporal overlap being the most important predictor of coherence. (ii) The effect of temporal overlap was no longer effective in the 0% spatial overlap condition, causing a significant interaction between the spatial and temporal effects. This demonstrates that even if distance, timing, and the information inside apertures are exactly the same, the perceived direction can be completely different depending on the spatial configuration.

◆ **New approach to the temporal constraint for apparent motion**

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The purpose of this study was to investigate the temporal aspect of apparent motion, especially the effects of exposure duration. Sixty-four frames of dot patterns (subtending 2 deg × 1.5 deg) were successively presented with no ISI on a computer-controlled oscilloscope. The stimuli were orthogonal projections of a rotating spiral made up of six dots. Each frame, called fullframe, was further divided into 2, 3, or 6 subframes. If all subframes were perceptually integrated into a fullframe, optimal apparent motion would be seen. The exposure duration of the fullframe was computed as the sum of the SOAs of the subframes. Three parameters were experimentally varied: SOA, number of subframes, and order of subframe presentation. It was found that exposure duration had an important role in the perception of optimal apparent motion. When fullframe duration ranged between 60 and 160 ms, subjects clearly reported the perception of a rotating spiral, even for SOAs ranging from 10 to 80 ms. This suggests that fullframe duration determines the organisation of apparent-motion perception.

◆ **Attentional modulation of motion perception**

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Motion coherence thresholds were measured for superimposed random-dot patterns translating in different directions. The paradigm of Raymond and Isaak (1998 *Vision Research* **38** 579–589) was used. Two brief motion episodes were presented sequentially, with the first episode being 100% coherent and the coherence of the second being adjusted to determine threshold. Unlike Raymond and Isaak, we used motion transparency: two superimposed orthogonal directions of motion were specified by dots of different colour. The same orthogonal motion directions were used in both episodes. Observers were asked to pay attention to the dots of one colour and judge their motion direction. We found that the coherence threshold for motion was (i) high when the direction of coherent motion in the second episode was equal to the inattended motion direction in the first episode, (ii) low when coherent motion direction in the second episode was equal to the attended motion direction in the first episode. Since the stimulus conditions did not vary, we suggest that this variation of coherence thresholds for motion may be due to the voluntary inhibition of a previously presented motion direction, a sort of negative priming effect in motion detection.

◆ **Monocularity and motion aftereffects**

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The motion aftereffect (MAE) can be induced in a stationary grating by prior motion of the gratings surrounding it, if no other features are visible (Swanston and Wade, 1992 *Perception* **21** 569–582). When the flanking gratings move leftward during adaptation, a leftward MAE is subsequently measured in the central grating. This MAE from induced motion was examined with surround motions in opposite directions in each eye. Monocular MAEs following (opposite) binocular adaptation were considered to reflect the contribution of monocular mechanisms: they lasted about 60% as long as control monocular MAEs. Similar results were obtained for successive (experiment 1) and simultaneous (experiment 2) presentations is of the oppositely directed dichoptic gratings. The results complement the estimates of binocular involvement in induced MAEs derived from interocular transfer studies (Wade et al, 1993 *Perception* **22** 1365–1380).

◆ **Coherent motion supported by attention evokes stronger MEG gamma responses**

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We examined magnetoencephalographic (MEG) gamma-band activity in humans manipulating attention to coherent motion by auditory distractors. After a simultaneous exposure to visual and auditory noise (a baseline), subjects had to attend to the first of two stimuli (either regular motion of bars or a tone sequence) presented asynchronously (SOA = 500 ms) for about 1 s each, monitor it, and respond to its offset. MEG recordings were collected in a 151-sensor whole-head system (CTF Systems Inc.). Correct trials that were free of eye movements and motor responses within a trial were processed. A spectral power analysis revealed an increased, relative to baseline, evoked 40 Hz MEG response with attended coherent motion. The enhancement occurred within the initial 50–250 ms from motion onset over the right occipital areas. Yet, when attention was captured by the auditory distractor and subjects neglected visual coherent motion, the increase was not observed. Our findings suggest that 40-Hz activity in the human visual cortex relates to perception of coherent motion that is supported by attention.

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◆ **Reaction times for motion onset of luminance and chromatic gratings**

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We measured RTs for detecting the onset of motion of sinusoidal gratings (1 cycle deg^{-1}), for various speeds ranging from 0.25 to 10 deg s^{-1}. RTs varied linearly with the inverse of speed ($r^2 > 0.9$, 6 subjects, 12 conditions), consistent with a simple critical-distance model that requires

that stimuli traverse a fixed distance of space for motion detectors to be activated. The critical distance (calculated from the slope of the linear regression of RTs against speed^{-1}) was different for luminance than for chromatic gratings, and depended on contrast. For luminance modulation it varied from 0.02 to 0.18 deg over a contrast range of 22% to 0.8%. For equiluminant red–green stimuli, critical distance varied from 0.04 to 0.36 over the same RMS cone-contrast range. The difference in critical distance explains the stronger contrast dependence for chromatic compared with luminance stimuli for motion-onset RTs (Burr et al, 1998 *Vision Research* **38** 3681); and, given the relationship between perceived speed and RT, it may also help to explain the slower perceived speed and contrast dependence of chromatic gratings.

◆ **Interstimulus interval luminance and the Ternus display**

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The Ternus stimulus is a bistable apparent-motion display. Generally, at short interstimulus intervals (ISIs), subjects report seeing element motion; at long intervals, subjects report seeing group motion. It has been reported that manipulation of the contrast polarity/luminance of the stimulus and/or ISI frames can lead to a change in response from element to group motion. In this study we re-examined the effect of ISI luminance relative to the luminance of the stimulus frame on the perception of group motion, both with and without reversal of contrast polarity of stimulus frames. The results give some support to earlier research indicating that increasing ISI luminance promotes group motion at shorter ISI durations. However, for short ISI durations, with stimulus frames of the same polarity, group motion responses were maximal for ISI luminance values between those of the background and the stimulus frame. The results of reversing contrast polarity within a cycle also suggest that it is the luminance of the ISI relative to the stimulus frame, rather than absolute luminance of the ISI, that promotes group motion. The results are discussed within the context of short-range and long-range processes for apparent motion, and perceptual completion across space and time.

◆ **Sensitivity to deviations in slant and tilt for surfaces displayed in structure-from-motion**

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Sensitivity to differences in local surface orientation was studied in two experiments. The stimuli were structure-from-motion displays—orthographic projections of a sinusoidal surface rotating around a vertical axis. A gauge figure (Koenderink et al, 1992 *Perception & Psychophysics* **52** 487–496) was superimposed on the simulated surface. The orientation of the gauge figure differed from the local surface orientation by a predefined value both in slant and in tilt. The results revealed that the differences in slant and tilt were detected independently of each other and with similar efficiency. Correct detection with 95% probability required a difference in slant or tilt of about 20°. The sign of the difference between the gauge figure and the surface slant had a significant effect on sensitivity. Sensitivity to differences in local surface attitude varied over the surface, but was independent of its convexity/concavity. Detection of differences in slant showed greater variability than detection of differences in tilt, while sensitivity to difference in tilt was impaired when the surface slant was small. The role of local surface primitives in surface reconstruction and representation is discussed.

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◆ **Relationship between motion transparency and colour transparency of equiluminous colour plaids**

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It has been well known that 'motion transparency' of equiluminous moving colour plaids can be perceived when two gratings constituting a plaid are independently modulated along different colour cardinal axes [L – M and S – (L + M)]. However, the data were obtained under the limiting condition that both colour gratings had been modulated across the neutral point (white) on the cardinal axes plane. We used 18 equiluminous colour gratings with an equal colour contrast modulated horizontally and vertically at eight positions on the cardinal-axes plane in order to make moving and stationary equiluminous colour plaid stimuli. Subjects reported whether motion transparency was perceived or not under the moving-plaid condition, and also reported whether colour transparency was perceived or not under the stationary-plaid condition. We found

that motion transparency and colour transparency occurred only when the two gratings were modulated along different directions with the orthogonality independent of those positions on the cardinal-axes plane. The perfect correlation between the results obtained with moving and colour transparencies suggests that the motion perception mode (transparency or coherent motion) could be already fixed before drifting. We also discuss decision factors in colour transparency from the point of view of additive-colour-mixture theory and opponent-colour mechanisms.

◆ **Amblygrams: images revealed by motion blur**

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When an image is set in motion relative to a human observer, it appears smeared to him or her. This phenomenon is called motion blur. It is now widely accepted that motion blur is due to visual persistence, that is an integration of the light array over time at the retinal level. Visual persistence can be modelled by convolution (Gosselin and Lamontagne, 1997 *Perception* **26** 847–856). Here, I describe a technique based on deconvolution (the inverse of convolution) for creating amblygrams. The term amblygram has been coined to designate an image containing a pattern, any pattern in fact, hidden under steady viewing condition and revealed by a specific motion blur. I believe that amblygrams will become important tools in motion blur, motion deblurring, and motion sharpening experiments. The basic idea is to deconvolve the image you wish to conceal. This deconvolved image is an amblygram because only the adequate convolution or motion blur can restore the original image. It is shown that amblygrams can always be constructed provided that three loose restrictions are satisfied. Several amblygram samples are provided.

◆ **Simultaneous masking by plaids and gratings: threshold elevation and threshold facilitation**

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The effects of simultaneous masking were explored at remote orientations over a broad range of spatial frequencies (SF). Contrast thresholds for vertical sine-wave gratings (SF = 0.5 to 22 cycles deg^{-1}) were measured by interleaved staircases and probit analysis in a 2IFC paradigm. Masks were 1 cycle deg^{-1} gratings or plaids with components oriented at ±45°. Stimuli had a diameter of 4 deg and duration of 100 ms, and mask component contrast was varied between 8% and 24%. Unlike in a previous report where 3 cycles deg^{-1} masks were used (Derrington and Henning, 1989 *Vision Research* **29** 241–246), the magnitude of threshold elevation (up to 18 dB) was found to depend on the Michelson contrast of the mask and not the number of mask components. For neither mask type did threshold elevation decrease as the test SF was made less than that of the mask, suggesting a common masking mechanism for test frequencies at and below that of the mask. At and above a test SF of 4 cycles deg^{-1} a region of broadly tuned facilitation of up to 3 dB was found. Similar facilitation effects have been noted before (eg Tolhurst and Barfield, 1978 *Vision Research* **18** 951–958), but not when test and mask differ in both SF and orientation.

◆ **A new illusion of relative motion**

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A new and intriguing type of illusion of relative motion is demonstrated. When subjects move a printed page of a certain periodic pattern across their visual field, they see a part of this pattern moving orthogonally relative to the rest of it. This illusory motion is not of a random oscillatory nature (cf the Ouchi illusion) but is in a fixed direction that can be predicted directly from the stimulus properties. Nor does it seem to be an aperture effect (cf the barber pole), as no explicit windowing is present in the stimuli. Neither is it likely that it is the artifact of particular eye movements, because it persists for monocular viewing and can be demonstrated for linear, rotational, and looming motions. In each of those cases, the appropriate stimulus is constructed out of a pattern of simple square textels rendered in monochrome. The relative motion emerges where textels change their contrast polarities. We present experiments that quantify the effect of this illusion. We also discuss whether the effect could be predicted by applying traditional spatial filters to the motion-blurred stimuli.

◆ **Velocity perception is affected by the Ebbinghaus illusion**

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We examined whether the apparent extent of motion affects speed perception. In the first presentation of each trial, a light dot travelled horizontally across central circles of one of the Ebbinghaus configurations (with small or large inducing circles). In the second presentation, observers adjusted the speed of a dot moving within the central circle only so as to match the speed perceived in the first presentation. For all stimulus speeds (1.3, 2.1, and 5.5 deg s^{-1}), matched speed with small inducing circles was systematically lower than with large inducing circles. The results suggest that perceived speed depends on apparent extent of motion: the larger the apparent framework the slower the apparent speed. They are consistent with the observation that the apparent trajectory of a dot revolving along a central circle of the Ebbinghaus figure affects speed estimation (Stucchi et al, 1996 *Perception* **25** Supplement, 136), and with formal predictions of transposition effects in visual motion [Sokolov et al, 1998 *Advances in Perception–action Coupling* Eds B Bril et al (Paris: Éditions EDK)].

◆ **Bandwidth characteristics of feature-tracking motion mechanisms**

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Phase congruency amongst Fourier components greatly affects perception of features in moving stimuli. We [Del Viva and Morrone, 1996 *Investigative Ophthalmology & Visual Science* **37**(4) S744] have previously shown that changing the phase of the fundamental harmonic of square waves induces feature motion (second-order motion) in counterphased gratings, and affects the perceived contrast of drifting gratings (first-order motion). Here we studied the spatiotemporal frequency dependence of phase-sensitive feature-tracking mechanisms, by filtering the stimuli in the spatial domain. We progressively removed the high-spatial-frequency harmonics from counterphased square waves, while measuring the phase dependence of feature motion of counterphased gratings, and the perceived contrast of the drifting gratings. For both stimuli the phase dependence was determined only by components near the fundamental: the first, third, and fifth harmonics were sufficient to reproduce all the effects obtained with the unfiltered stimulus. These findings suggest that the complex behaviour of this phase-dependent mechanism can be fully explained by a limited number of components, with a spatial bandwidth of about two octaves.

◆ **Effects of remote motion on the visual sensitivity of LGN cells**

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Sudden displacements of remote images induce visual sensitivity loss in humans and felines [MacKay, 1970 *Nature (London)* **225** 90–92; Derrington and Felisberti, 1998 *Vision Neuroscience* **15** 875–880]. We investigated the effect of remote image motion on the responses of LGN cells of marmosets to stimuli presented to their classic receptive field. The stimuli consisted of brief, stationary central targets (spots) of optimal size and polarity, flashed either alone or in the presence of a peripheral annulus containing a low-spatial-frequency grating displaced at saccade-like velocities (shift). We measured how the d' of relay cells varied with the contrast of the spot, in the presence or absence of the shift. In the presence of a remote shift, the contrast of a spot displayed to magnocellular neurons has to be raised by about 1 log unit to reach a $d' = 2$ ($p < 0.01$; t test), while the sensitivity loss induced by the shift in parvocellular neurons was 0.6 log unit ($p < 0.02$). Analysis of cell eccentricity showed that the shift affects more strongly magnocellular neurons inside a central radius of 5 deg. These results show that visual signals arising outside the classical receptive field reduce the contrast sensitivity of primate LGN cells and may be involved in saccadic suppression.

◆ **Motion and depth modulate the hierarchical organisation effect**

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When a vertical rod is presented within a tilted square frame, it is perceived, according to the frame-of-reference effect, to be tilted in the opposite direction to the frame tilt. In central double-frame displays (DFDs) a vertical rod is presented within two concentric square frames, the outer

tilted and the inner upright. Observers perceive the vertical rod tilted in the same direction as the outer frame. This finding has been attributed to hierarchical organisation (HO) (Zoccolotti et al 1997 *Perception* **26** 1485–1494). Only the illusory tilt of the inner frame, induced by the outer frame, influences the perceived orientation of the rod. In previous studies with DFDs, we used a forced-choice procedure, which commonly produces results equivalent to the adjustment method. Here we report a difference between the two methods. The adjustment procedure fails to produce the HO effect. We hypothesise that this result is due to the DFD not being perceived as a single object. Motion breaks the relation between the rod and the inducing stimuli and a frame-of-reference effect is shown. In order to evaluate this hypothesis, we have conducted a series of experiments using stereoscopic DFDs to segregate the elements by depth.

◆ **Perceived depth of a random-dot stereogram in oscillatory motion**

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Under conditions which create the percept of a random-dot stereogram in oscillatory motion, the stereodepth is known to diminish and eventually reach zero at higher frequencies (Shipley et al, 1984 *Documenta Ophtalmologica* **58** 269–305). We studied the onset of this process and demonstrated that the initial stages (0–2.5 Hz) are far from being gradual or monotonic. Our targets were formed by paired spots of polarised light and viewed through a rotating ocular polariser. A sharply reduced amplitude of perceived oscillations was noticed at 0.8 Hz. For higher frequencies the crossed-disparity depth almost recovered its initial value while the uncrossed-disparity view of a target was never seen. The present investigation demonstrates that the sharp minimum in depth sensation and the rectification of perceived oscillations are associated with retinal excitation modulated in intensity as $\sin^2 \omega t$. Viewing conditions were altered to generate a train of either exclusively crossed or exclusively uncrossed disparity pulses with the time exposure matching any frequency within the 0–2.5 Hz range. The perceived motion remained periodic, but the brain input lost the distinct characteristics of $\sin^2 \omega t$. This resulted in elimination of both effects: uncrossed disparity pulses were perceived at all frequencies, and crossed disparity no longer displayed a minimum.

◆ **Velocity matches support a suppression-from-depth model of motion integration**

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We studied the apparent velocity of surface contours appearing either in front of or behind another surface, in three kinds of configuration: the barber-pole effect, paradoxical rest (Gerbino and Bruno, 1997 *Perception* **26** 1549–1554), and illusory figures. To control fixation, vergence, and binocular disparity, each trial in each experiment consisted of three parts. First, a small probe was presented for a depth-adjustment task. After the adjustment, the edge in the standard display was moved (duration ca 204 ms) at one of several physical speeds. Finally, a comparison edge was presented (also lasting ca 204 ms). Matches derived from 2AFC velocity judgments were essentially consistent with the idea that motion signals on the same perceived depth plane as a target edge are integrated, whereas motion signals on a different perceived depth plane than a target edge are suppressed; ie they are consistent with the suppression-from-depth model of motion integration (Shimojo et al, 1989 *Vision Research* **29** 619–626).

◆ **Temporal integration of optic flow**

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We measured both signal-to-noise thresholds and contrast sensitivity for discerning the direction of motion of random-dot patterns moving in circular, radial, or translational motion, as a function of exposure duration. Signal-to-noise thresholds were measured for three conditions: the stimulus alone, the stimulus embedded within a 10 s exposure of random noise, and a 200 ms stimulus embedded within a noise patch of variable duration. With the simple presentation, sensitivity increased with the square root of duration up to about 2 s, and more gradually thereafter, suggesting a neural integrator with a 2 s time constant. When the stimulus was embedded within 10 s of noise, sensitivity increased more rapidly, approximately linearly with duration, again up to about 2 s. When the duration of the flanking noise was varied, sensitivity decreased with total duration over a similar interval. On the other hand, contrast sensitivity for these patterns increased linearly with exposure duration, up to only about 100 ms, consistent with previous estimates of temporal summation of early motion units. We interpret our results to reflect two stages of analysis,

a threshold-limited early stage of local-motion analysis, with a time constant of 100 ms; and a later global-motion integration stage, with a much longer time constant, around 2000 ms.

◆ **Heading detection from optic flow with roll and pitch components**

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We investigated the effects of roll (rotation around line of sight) and pitch (rotation around the horizontal axis) components in retinal flow on heading judgment from visual information alone. Situations where an observer moved toward a cloud-like structure in the 3-D environment while fixating a static point were simulated to generate a retinal flow field of random dots. The subjects' task was to point out the perceived direction of heading. We found that human observers can perceive heading not only with yaw (rotation around the vertical axis) but also with pitch. However, the subjects showed some bias in perceived heading toward the fixation point. We also found that human observers can judge heading accurately from retinal flow with pitch, yaw, and roll components at a roll rate of 11.5° s^{-1} when heading toward a 1000-dot cloud with the large depth range was simulated, though some bias in perceived heading to the fixation point was observed.

◆ **Pleasantness of 3-D motions: effects of motion direction**

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We investigated pleasantness and other subjective aspects of computer-generated 3-D motions. Using a SGI display we presented 50 spheres moving in one of eight directions, 45° apart, at about 10 cm s^{-1}. In a 2-D control condition disks replaced spheres. Observers chose the most and least pleasant directions (test 1) and rated their impressions on a semantic differential scale (test 2). In test 1, observers had the most pleasant impressions when they felt themselves moving upward and the least pleasant impressions when they felt themselves moving downward. These results were different from the results for the 2-D control condition in which observers chose the rightward motion as the most pleasant because they could easily follow it. Test 2 data allowed us to identify four factors (mildness, reality, health, safety), instead of the three factors (activity, potency, evaluation) suggested by Osgood et al [1957 *The Measurement of Meaning* (Urbana, IL: University of Illinois Press)]. We conclude that the stronger effects of 3-D motion graphics are associated with ego-motion along the vertical.

IMAGING, PHYSIOLOGICAL, AND CLINICAL STUDIES

◆ **Which image features are selected by neurons of the cat primary visual cortex**

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About 40% of neurons (114/289) in cat primary visual cortex (area 17) gave a larger (by a factor of 3.06 ± 0.32 on average) response to a flashed cross, corner, or Y-shaped figure centred in the receptive field than to a single bar of preferred orientation. Most such neurons (72%) were highly selective both to shape and orientation of figures, but we have also found neurons with an invariance of tuning to the figures, orientation, and/or shape. Cross-sensitivity was investigated also in 85 striate neurons before, during, and after local blockade of intracortical inhibition by microiontophoretic application of bicuculline. Inhibition either increased cross-sensitivity, or depressed it. Possible mechanisms of figure sensitivity are discussed as well as its functional implication for a second-order feature extraction in the striate cortex.

◆ **Simulation of the dynamic behaviour of neuron activity**

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The responses of single neurons or neuronal pools of the cat lateral geniculate body to the presentation of visual stimuli with various spatial brightness parameters were investigated. Power spectrum analysis methods were used for the evaluation of the influence of the stimulus properties upon appearance and development of gamma waves (20–80 Hz) in the neuronal pool responses. The gamma waves appear when the neuronal activity exceeds a specific neuronal threshold. When the activity level decreases in consequence of the change of the stimulus parameters, several additional peaks arise in the response spectrum, and the spectrum shape resembles that of

chaotic systems. Quantitative evaluation of stimulus-evoked synchronisation has been obtained by dimensional analysis (see Grossberg, 1988 *Physiological Review A* **38** 1649–1652). We propose a mathematical description of gamma oscillations based on the nonlinear transformation which is characteristic of an intermittent transition to deterministic chaos. Model predictions are in good agreement with the experimental data.

◆ **Visual discrimination learning characteristics in monkeys with bilateral prefrontal cortex**
A099 lesions

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The characteristics of learning processes involving visual discrimination of stimuli with different shape, size, colour, spatial frequency, and orientation, as well as complicated two-dimensional scenes with various spatial-relationship features, were studied in experiments on two groups of rhesus monkeys. The prefrontal cortex sulcus principalis was removed bilaterally in animals of one group. The remaining animals served as unoperated controls. Monkeys' decisions and motor reaction times were recorded. Bilateral extirpation of sulcus principalis did not influence the learning characteristics for orientation and spatial-frequency discrimination. On the contrary, the duration of the learning process and reaction times significantly increased in the monkeys, after the bilateral lesions of sulcus principalis, for discrimination of visual stimuli connected with size, and some types of shape and spatial-relationship features. Furthermore, learning to discriminate stimuli with different colour was dramatically impaired. As a result, duration of the learning process and reaction times sharply increased, and the level of correct decisions after training significantly decreased. These results suggest that prefrontal cortex sulcus principalis is involved in the mechanisms associated with higher-level cognitive processes which are related to visual awareness and which are caused by interactions between prefrontal cortex and more posterior brain regions.

◆ **A model of simple-cell contrast processing and normalisation in the mammalian visual cortex**
A100 J S Lauritzen, D J Tolhurst (Department of Physiology, University of Cambridge, Downing Street, Cambridge CB2 3EG, UK; e-mail: jsl20@cam.ac.uk)

The range of contrasts in the natural world far exceeds the dynamic range of any single neuron in primary visual cortex. We have investigated the range of contrasts present in natural scenes, and the ability of contrast normalisation to match the dynamic ranges of neurons to prevailing contrast conditions. Gabor patches were used to simulate simple-cell receptive fields. These were convolved with digitised monochrome photographs of natural images, and the result divided by the average luminance in the receptive field, to obtain the contrast response. The normalised response was obtained by dividing this contrast response (after squaring) by the mean squared responses of all receptive fields at the equivalent location. We also compared the responses obtained for pictures of the same scenes under direct and overcast sunlight. The total contrast (ie the source of normalising signal) varied by a factor of three to four at different locations in different scenes. Variation between bands in the same scene was up to a factor of two. Direct sunlight increased contrast by up to 30% over the overcast condition. Contrast normalisation was effective at reducing these ranges, and especially at matching the direct-sunlight condition to the overcast.

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◆ **Cell segmentation with local adaptive thresholding**
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The study of cell movement is fundamental to research in embryological development, wound healing, immune defense, tumour cell invasion, and metastasis. Cell migration is conventionally monitored by using time-lapse microscopy in combination with different 2-D or 3-D tissue substrata. For the detection of changes in cell shape and/or relative position with time from serial images, a precise and robust segmentation procedure is required to discriminate between the cell boundary and the surrounding tissue. I present an efficient segmentation algorithm for different cell types: pre-processing by a rational operator is combined with local adaptive thresholding within a local adaptive window surrounding each cell, and post-processing with morphological operation leading to a visual separation of neighbouring cells.

◆ **The pupillary light reflex in Alzheimer's disease**

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The finding of neurofibrillary degeneration in neurons of the Edinger Westphal nucleus in Alzheimer's disease (reported by Hunter, 1985 *Acta Neuropathologica* **68** 53–58) prompted us to ask whether the reflex pupillary constriction to light (which includes the Edinger Westphal nucleus in its anatomical pathway) would display functional abnormality in Alzheimer's disease. Three groups of individuals were tested: 12 healthy young people, 12 people with probable Alzheimer's disease, and 12 healthy older adults. The pupillary light reflex was measured with a head-mounted infrared pupillometer. As the Edinger Westphal nucleus is particularly involved with pupillary constriction we predicted that the amplitude of pupillary constriction would be reduced in Alzheimer's disease compared to normal ageing. Our results confirmed this prediction. As the Edinger Westphal nucleus is cholinergic in nature, the measurement of pupillary constriction may provide a way of indicating change in central cholinergic status in Alzheimer's disease over time or in response to drug treatment.

◆ **Does spatial-frequency spectrum of singular TV frames affect VEPs?**

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The aim of this work was to investigate responses of the human visual system to sets of singular TV frames consisting of images with different spatial-frequency (SF) properties. We measured human VEPs to the sequence of sine-wave gratings with the spatial frequencies of 0.4, 0.8, 1.6, 3.2, 6.4, 12.8 cycles deg^{-1}. Gratings were presented in an ON–OFF mode. The frames were organised in sets. We used not less than three frames for one grating. The sets were organised in sequences. The first sequence started with the lowest SF, then, in increasing order, to the highest SF. The second sequence was reversed. The third sequence was random. The SF characteristics were obtained by first and second harmonics of VEP amplitude to each set in the sequence. Not only SF but also the order of presentation was crucial to VEP amplitude in the first experimental sequence. If the lowest SF was first, the VEP response dominated. In the second and third sequences only the SF of gratings affected the response. The SF characteristics obtained from the second and third sequences correlated with psychophysical results. The results are extrapolated to natural images in TV viewing.

◆ **Functional imaging of brain areas involved in the wide-field visual processing of continuous linear self-motion**

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A PET study was performed to examine the brain areas involved in processing linear self-motion. This experiment's distinguishing characteristic was its use of a very wide collimated display to approximate the optical characteristics of locomotion through an ambient scene. Subjects viewed four conditions. The first depicted coherent expansion, corresponding to steady forward movement (EXP). The second depicted contraction, corresponding to reverse movement (REV). In the third, control condition (CON), the instantaneous screen size and speed of the stimulus elements were appropriate to their distance and eccentricity (assuming the locomotion speed depicted in EXP and REV), but their assigned directions were random. The fourth condition was a static scene (STAT). Change distribution analyses were performed on voxel-by-voxel subtractions between averaged images of the conditions. Wide-field motion elicited medial-occipital activity in both the coherent (EXP, REV) and incoherent (CON) motion conditions, relative to STAT. This increase was limited in the EXP condition, and more widespread in the REV and CON conditions. The subtraction (EXP – CON) indicated vestibulo-cerebellar and bilateral temporal response specifically to coherent forward motion. Importantly, minimal change was observed in V5/MT. The results are consistent with the operation of multiple neural pathways for different visual motion configurations.

◆ **Epilepsy-related visual disorders**

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Epilepsy is characterised by recurrent unprovoked seizures occurring more than 24 hours apart and can impair not only elementary visual functions but also higher cognitive visual abilities. We examined 300 patients suffering from epilepsy in the Kaunas Academic Clinics, Lithuania. The majority of these patients suffer from temporal/occipital epilepsy, as revealed from EEG data and their processing with the use of spectral and AR model analysis. Patients with right and left damaged temporal/occipital lobes of the brain were examined by using a test developed by Ruseckaite (1998 *Perception* **27** Supplement, 164). One third of these patients showed visual perception disorders related to ability to judge size and shape of two-dimensional figures.

◆ **The relationship between sparseness and kurtosis of simple-cell codes**

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The kurtosis of the response distributions of basis functions is often used to evaluate models of simple-cell coding of natural image information. Kurtosis is assumed to be a good indicator of the sparseness of codes. However, sparseness need not produce kurtosis, and high kurtosis need not indicate sparseness. For example, kurtosis is influenced by the variance distribution of image sets (Baddeley, 1996 *Network* **7** 409–421).

We have compared kurtosis values produced by models of simple-cell coding in visual cortex: PCA, ICA, and the 'sparse coding' model of Olshausen and Field (1997 *Vision Research* **37** 3311–3325). We find that kurtosis is dependent not only upon the model per se, but also upon any pre-processing (eg spectral 'whitening') which is applied to images. Various types of pre-processing are used, either for pragmatic reasons, or because they model retinal image processing. We find that the most physiologically plausible pre-processing techniques—those which model the contrast dependence of retinal pre-processing—reduce kurtosis considerably.

We have also compared kurtosis values with other, more direct measures of sparseness, to try to elucidate the relationship between sparseness and kurtosis, and to develop a more robust measure of sparseness.

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◆ **Cognitive factors related to the Pokemon mass seizure incident in Japan**

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On 16 December 1997 about 700 people, mainly schoolchildren, were taken to hospitals after feeling sick while watching a TV cartoon of the Pokemon (Pocket Monsters) series. This is known as 'the Pokemon incident'. Many experts attributed the main cause of it to a 12 Hz red–blue flicker scene lasting about 5 s. It is well known that some physical attributes of the visual stimulus (eg flicker) can be detrimental to photosensitive people, or people vulnerable to visual stress [Wilkins, 1995 *Visual Stress* (Oxford: Oxford University Press)]. However, we think that cognitive factors also played a critical role in the incident. To investigate such factors, we asked normal adults to estimate the magnitude of visual stress induced by scenes selected from the Pokemon show and varied subjects' knowledge of the story plot. We found that the estimated amount of visual stress depended on cognitive factors. Subjects who knew the plot estimated the effect as significantly stronger than those who did not know the plot.

◆ **Thresholds of visual field changes in damage of chiasma opticum**

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Impairment of achromatic visual field thresholds in special sectors of peripheral visual field was measured in persons with pituitary adenomas, which present clinical signs of space-occupying lesion in the lower side of chiasma opticum. Thresholds of peripheral inner upper and lower, and outer upper and lower sectors of visual field of each eye of 16 patients with pituitary adenomas were measured before and after their removal. Computerised Humphrey perimeter with standard stimulus size was used and 68-point peripheral visual field screening with quantity defects strategy was performed in two outer and two inner sectors of each eye. In common cases of chiasmal syndrome, thresholds of visual field usually are reduced in outer sectors of visual field. In our cases achromatic sensitivity thresholds measured in decibels by using quantity defects strategy were

reduced not only in outer upper sectors of visual field (10.2% of cases) but also in inner upper sectors (6.2% of cases). These data refer that detection of achromatic visual field thresholds in cases of damage of chiasma opticum is useful to detect localisation of this damage.

◆ **Sensorimotor and cognitive development in twins with different visual status**

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Investigation of the role of visual experience in human development always faces the problem that significant individual differences in subjects make it impossible to establish the nature of the contribution of vision. In order to remove factors that cause these differences we studied the role of vision in early sensorimotor, cognitive, and behavioural development—three pairs of MZ twins. In each pair one of the twins had only light perception (diagnosis: acute retinopathy of prematurity), and the other one had normal vision. The infants were tested at the corrected ages of 4, 8, 12, 18, 24 months in home conditions by a special test procedure (developed on the basis of the Bayley Scales of Infant Development). Consistent lags in the general development of infants with severe vision impairment were confirmed. Under the age of one year this delay was identified as being due to such items as "inspecting surroundings", "turning head to sounds", "lifting head", "turning from back to side", "reaching to sound objects". At the same time in items relating to body scheme and object concept, differences between practically blind infants and those with normal vision were not observed. These results demonstrate that vision stimulates motor development and investigative activity. It allows integrating information from different sources. Up to the age of one year this could be seen in the impaired infants' lagging behind in fine motor development and in tactile identification of spatial shapes as well as in peculiarities of their behaviour.

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◆ **Prism adaptation after parietal lobe damage: a developmental single-case study**

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We investigated the pointing movements made by a child (DC) with a stroke in the parietal area to support evidence about the relationship between impaired sensorimotor behaviour and brain damage. The role of vision and proprioception in motor action is well recognised. In addition, Clower et al [1996, *Nature (London)* **383** 618–621] provided neurophysiological evidences that the spatial receptive fields of many neurons in the posterior parietal cortex are modulated by voluntary motor activity. We used a pointing task and a visual perturbation, asking for a movement as accurate as possible to control the movement and the nature of strategic control. The data are discussed in relationship with the aftereffects observed at the removal of the prisms and the measures before and after prism exposure, as suggested by Redding and Wallance (1996 *Journal of Experimental Psychology: Human Perception and Performance* **22** 379–394). The role of the feedforward commands (which direct the hand to the target) has been analysed, attention being paid to the accuracy and movement trajectory as a result of motor representation programmed by comparison of visual information and information about arm configuration.

◆ **Impaired access to visual representations of animals: a constructional deficit**

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Neuropsychological cases of semantic memory disorders have been described in the past, featuring a dissociation in the knowledge of living and nonliving entities. A previously unreported pattern of a similar dissociation, regarding animals, is reported here. PM is a 40-year-old painter who suffered a vascular injury in the right frontotemporal region. Unlike typical cases, PM names well all types of stimuli, including animals and shows an excellent verbal encyclopaedic knowledge, including that of both functional and structural features of given items. In contrast, while making excellent drawings of complex objects and of other living entities like fruits and vegetables, she makes very bad drawings of animals and geometrical figures, even on copy. Furthermore, she is unable to complete partial drawings of animals only, while she satisfactorily completes partial drawings of objects. This dissociation holds in the recognition of chimerical figures of animals (preserved) rather than of objects (impaired). A possible interpretation of this phenomenon is that of a disturbed activation of a domain-specific structural memory for constructional purposes.

In partial keeping with Warrington and Shallice's theory of semantic memory, this disturbance is thought to be sufficient to affect more the building of configurations from the domain of animals.

◆ **A specific deficit for global processing of spatial structure**

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We have studied a patient with early Alzheimer's type dementia who shows profound and selective impairment in the perception of global spatial configurations, with minor general cognitive or perceptual deterioration. MRI scans show a mildly atrophic cortex, with a significantly pronounced enlargement of the sulci at the level of the parieto-temporal junction in the right hemisphere. Both standard neuropsychological tests and quantitative psychophysical measurements show severe impairment for all tasks requiring global synthesis from local elements. She is completely incapable of seeing 'hierarchical letters' (letters made up of smaller letters), of seeing structure in the most obvious radial or circular glass patterns, of perceiving Kanizsa figures of any kind, and has difficulty perceiving simple figures made from aligned Gabor patterns in noise. Where thresholds could be measured, they were at least more than an order of magnitude higher than the norm, while a series of tasks not requiring global integration were within standardised norms. Most interestingly, she could not see biological motion, even after extensive prompting, although thresholds for optic flow were within normal limits. The study suggests the existence of a specific neural substrate for perceiving global spatial structure, whether derived from static elements or from local motion.

◆ **Asymmetry in visual system and myopia**

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We studied asymmetries of visual analyser characteristics in ophthalmologically normal volunteers and in subjects with myopia. Refraction and eye sizes showed no lateralisation in both studied groups. Symmetry was sharply broken in factors characterising the functional condition of the retina and of the optic nerve of patients with shortsightedness, although the absolute values of these parameters stayed within the norm. Ganzfeld-ERG amplitude of the right eye of myopic patients was higher than that of the left, whereas local-ERG amplitudes were higher for the left eye. Amplitude and temporary characteristics of the main components of VEP were similar in the explored groups. The focus of maximum amplitude of early VEP components in the occipital area (P100) of patients with shortsightedness was displaced in the left hemisphere, whereas we noted symmetry of this component in the group without myopia. In addition, the group of short-sighted patients was characterised by a significant reduction (practically an absence) of the N150 component, which is clearly present in parieto-temporal and occipital abductions of the right hemisphere of the normal volunteers.

◆ **Psychophysical evidence for the role of an oscillatory (38 – 40 Hz) mechanism during visual**
A114 feature – object coding

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Recent neurophysiological studies indicate that the synchronisation of spatially distributed neuronal assemblies at around 40 Hz in the visual cortex is connected with binding the separate feature elements of a figure or an object. Using a novel 'premask paradigm' we found frequency-specific, reaction-time (RT) synchronicity priming of Kanizsa-figure presentation, which, consistent with the neurophysiological findings, was only obtained when prime stimuli were presented within premask matrices that oscillated at between 38 and 40 Hz. Further experiments have shown that synchronicity-priming RT effects persist for up to 150 – 200 ms between 40 Hz premask-display offset and target-display onset. Within the 150 ms duration of the 'synchronous prime', RTs were found to be sensitive to the precise temporal relationship between premask display and target display presentation: specifically synchronicity-priming RT effects were maximal when the target was presented out-of-phase with the 40 Hz presentation frequency of the premask. Taken together, these findings not only demonstrate the relevance of synchronisation for figure coding, but also provide the first, direct psychophysical evidence for a mid-gamma-band figure-coding mechanism in the brain. Finally, electrophysiological (EEG) recordings of brain activity during 40 Hz premask presentation have confirmed that patterns of 40 Hz activity in occipital and temporal electride sites correlate significantly with the RTs to targets preceded by a synchronous prime.

◆ **Visual activity is under control of gaze direction in primate area V1**

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We have shown previously (Trotter et al, 1992 *Science* **257** 1279–1281; 1996 *Journal of Neurophysiology* **76** 2872–2885) that disparity selectivity in area V1 is modulated by the viewing distance. The question arises if that result can be generalised in the frontoparallel plane. Two monkeys were trained to perform a visual fixation task at three different positions on the horizontal meridian: straight ahead (0°) and 10° right and 10° left of straight ahead. Horizontal disparity and orientation selectivity were tested in identical retinotopic positions at the three directions of gaze within 4° of the foveal projection. For both disparity and orientation studies, changes in gaze direction produced significant changes in visual response in about half of the neurons: 54% ($n = 67$) of cells tested for disparity and 50% ($n = 104$) of cells tested for orientation. The main effect was a significant change in the evoked firing rate (gain) in 72% of these cells studied for disparity and 85% of those tested for orientation. Shifts in preferred disparity angle were observed in 17% of cells. Our results show that neural features of area V1 are expressed within restricted particular regions of extrapersonal space depending on eye position. We thus propose that cortical mechanisms for spatial location start as early as area V1.

◆ **Selectivity of macaque inferior temporal neurons for shapes with different surface attributes**

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Objects are easily recognised despite a large variability in their attributes. We tested how responses of inferior temporal (IT) neurons of macaques changed for figures with different surface and contour information. The same set of figures was presented to fixating monkeys as coloured pictures (COL), line-drawings (LD), silhouettes (SIL), illusory contours (IC), while extracellular single-cell activity was recorded from 105 neurons of the anterior part of IT. Most of the 87 neurons responsive for COL were also responsive for the same shapes, presented as LD (85.2%), SIL (85.2%) or IC (72.2%). The average firing rates, however, were significantly lower for LD, SIL, and IC stimuli, than for the COL condition. 79% of the COL-responsive neurons were shape selective for COL; and 64%, 57%, and 33% of these neurons were also selective for the same figures when presented as LD, SIL, and IC, respectively. The shape preference of the neurons was the same for COL, LD, and SIL. Our results suggest that IT neurons selective for shapes independently of the presence of colour, texture, or internal contour may form the neuronal basis for the invariant recognition of objects with reduced surface information.

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◆ **Structural organisation of visual projections in the cat cortical areas**

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Methods based on retrograde transport of labels have essentially extended our knowledge of organisation of the thalamo-cortical connection in the visual system. However, in view of certain methodological peculiarities, there are many discrepancies on this issue. The purpose of the present work was to make a comparative analysis of data obtained by retrograde transport of primulin and horseradish peroxidase (HRP). Local injections of these labels were made in cortical areas 17, 18, 19, C-B zone and association fields 5, 7, 21 of temporal region. The abundance of labelled cells after injection of primulin made it possible to reveal retinotopically organised and diffuse systems of connections in geniculo-cortical and extrageniculo-cortical projections. A considerably smaller number of cells was labelled by HRP. Unlike primulin, HRP reveals preferential connections with definite topical organisation of (i) A-A1 layers of GLd with area 18, (ii) LP-Pul of nuclear complex with area 17, (iii) pretectal nuclei with area 19 and C-B zone. The peroxidase method fails to reveal direct connection of CS with temporal association cortical areas. The revealed neuronal connections may offer an explanation of the basic phenomena for understanding the mechanisms of reciprocal subcortico-cortical interaction of the visual system.

◆ **Long-range neuronal connections in cortical areas 17 and 18 of the cat**

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Intrinsic neuronal connections within areas 17 and 18 in cat visual cortex were investigated by microiontophoretic injections of horseradish peroxidase to single cortical columns of cells. Serial frontal brain sections were used to obtain the 3-D reconstruction of the retrogradely labelled

cells region. Areal distribution of labelling (in a tangential plane) was elongated in area 17 along the representation of the horizontal meridian of the visual field and in area 18 along the representation of the vertical meridian. The dimensions of the labelled cells region did not depend on the location of the injected column in the visuotopic map. The regions with labelled cells in the supra- and infragranular layers were in register. Thus spatial distributions of intrinsic connections in these areas are orthogonal and coincide with the well-known spatial distributions of input fibres to these areas from the lateral geniculate body. Obtained morphological data suggest that detailed analysis of horizontal and vertical components of visual image may be carried out separately in cortical areas 17 and 18.

◆ **Digit-Stroop and cognitive interference: a psychophysical study preliminary to fMRI**

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Selective attention is required in tasks that involve the inhibition of competing responses. When the processing of one stimulus attribute impedes the processing of a simultaneous second stimulus attribute, then cognitive interference occurs. The colour-Stroop task is the prototypical interference task used for studying the basic mechanisms of attention and cognition in both normal subjects and patients with neuropsychological impairments (Stroop, 1935 *Journal of Experimental Psychology* **18** 643–662). In order to determine, with fMRI, the underlying neural substrate of cognitive interference, a Stroop-variant task (digit-Stroop) that obviates problems produced by speaking was tested. Two experiments were run. For both of them, subjects were required to judge the larger (on the relevant dimension) of two simultaneously displayed digits. In one session, the relevant dimension was numerical size, and in the other session, it was the physical size. Three types of stimuli were used: congruent, incongruent, and neutral. Error rates and RT data were analysed. In the first experiment, physical size and numerical distance were manipulated with the purpose of selecting the stimulus features that produced the strongest interference effect. A selection of conditions was tested in a second behavioural experiment and will be studied with fMRI.

◆ **Spatiotemporal dynamics of long-range interactions in a model of primary visual cortex**

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Recent physiological studies have shown that spatial and temporal context of visual stimuli can modulate the responses of primary visual cortex (V1) cells. The influence of peripheral activation has been found to depend on the relative orientation and contrast of the pattern elements inside and outside the classical receptive field (CRF). It also decreases in strength at increasing distances from the CRF while its latency increases (Bringuier et al, 1999 *Science* **283** 695–699). The present large-scale detailed model of V1 extends previously proposed mechanisms for extra-CRF excitatory and inhibitory modulations (Somers et al, 1998 *Cerebral Cortex* **8** 204–217) by investigating the role of long-range lateral connectivity in the spatiotemporal characteristics of subthreshold integration fields. The model accounts for orientation-selective suprathreshold responses and for the radial spread of subthreshold activation evoked by a focal stimulus in the cortex. It is then used to explore the spatiotemporal characteristics of the summation mechanisms between direct thalamocortical activation and subthreshold horizontal synaptic inputs in situations of simultaneous and/or successive stimulations at different distant locations in the cortex. The results are compared with physiological data as well as with the psychophysics of contour extraction, lateral masking, and apparent speed experiments.

◆ **Cortical areas underlying motion perception during smooth pursuit**

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We measured fMRI responses during fixation and pursuit while subjects performed a coherent motion detection task. Eye movements were monitored inside the scanner with our newly designed MR-Eyetracker (Kimmig et al, forthcoming *Experimental Brain Research*). Imaging was performed with a 1.5 T whole-body Siemens Magnetom (Vision) equipped with a gradient system having 25 mT/m amplitude and 0.3 ms risetime. Sixteen 4 mm planes, positioned oblique to the axial plane, were imaged every 4.3 s by using a T2*-weighted sequence (TE = 66 ms, flip angle = 90°, FOV 256×256 mm^2, 128×128 voxels). Limited-lifetime random-dot kinematograms

(380 white dots—diameter = 11.25 min of arc, 2% density—on dark background) with 0%, 4%, or 16% motion coherence were presented during a trial lasting 33 s. Subjects responded in a 'yes–no' paradigm, whether coherent motion was presented. BOLD responses and performance were compared under conditions of static fixation versus smooth pursuit (central white dot with diameter = 15.75 min of arc). During the pursuit task, the central fixation dot moved sinusoidally in-phase with the coherent dots. The results indicate that the BOLD response in motion-selective areas is significantly larger during pursuit. In comparison, the effect of motion coherence on the BOLD response is much smaller.
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◆ **Evoked potential source mislocalisation due to uncertainties in lesion type identification**

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Dipole source localisation by means of visual, auditory and somatosensory evoked potentials (EPs) recorded from the scalp is widely used to estimate the location of sources of electrical activity in the brain from which we can infer about brain's functioning. This localisation technique relies on a model of the source and a conductive model of the head. In neuropsychological experiments a dipole model can represent the actual EP source, but in presence of a brain lesion the conductive model of the head must embed also the lesion which is normally neglected. Lesion parameter identification is often wrong: in MRI scans bone and fluid are indistinguishable but their electrical properties differ up to 300 times. The results of our simulations show that the electric potentials measured on the scalp surface are significantly influenced by lesion parameters. Therefore, uncertainties in lesion type identification cause large source localisation errors either in position (up to 2 cm) or in intensity (up to 100 times) on more than 50% of the test conditions. We show that by solving the forward bioelectric problem and analysing the recorded (simulated) EPs it is possible to reduce or eliminate this error.

◆ **Visual motion detection in man is governed by nonretinal mechanisms**

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Generally, it is assumed that there is no substantial motion-specific processing in the primate retina. To test this specifically for humans, we simultaneously recorded visual evoked potentials (VEPs) from three scalp positions (Oz and 5 cm left/right) and electroretinograms (ERGs) to visual motion onset of an expanding or contracting 'dartboard' (34 deg; 98% contrast; 22 deg s^{-1}). To assess the proportion of motion-specific responses in cortex and retina we tested the direction specificity of motion adaptation with three conditions in a fully balanced paradigm. We measured motion-onset potentials after adaptation to (1) a stationary pattern (baseline), (2) motion in the same direction as the test stimulus, and (3) motion in the opposite direction. Motion-onset responses in the VEP were dominated by the typical N2 at 150 ms, in the ERG by a positivity at 70 ms. Motion adaptation produced strong direction-specific effects in the VEP, but not in the ERG: in the adapting and nonadapting directions the VEP (N2) was reduced by 90% and 54%, the ERG by 36% and 28%, respectively. The striking difference of the direction specificity of motion adaptation between cortex and retina suggests that in humans the vast majority of motion-specific processing occurs after the retinal ganglion cells.

◆ **Coding of simultaneous and successive luminance contrast by component P120 of visual**
A124 evoked potentials in humans

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We investigated foveal visual evoked potentials (VEPs) to test–surround luminance-contrast patterns in two human subjects, and VEPs to successive luminance contrast in other two subjects. To study simultaneous contrast, a 2 deg test disk was presented on a 12.5 deg × 9.5 deg surrounding field. Nine achromatic test disks differing in the 1–100 cd m^{-2} luminance range were combined with five different achromatic surrounds to produce luminance contrasts varying from −98% to 98%, with a minimal absolute value of 15%. To study VEPs to successive luminance contrast one stimulus was replaced by another. Nine luminances in the 1–100 m^{-2} range were used to generate 72 stimulus combinations. Only positive components of occipital VEPs with peak latencies of about 120 ms (P120) were connected with both kinds of achromatic contrast changes. In occipital, parietal, and inferotemporal electrodes the P120 amplitude exhibited a U-shaped dependence on contrast. The P120 amplitude increases progressively with both positive and negative contrast. Results suggest the existence of a neuronal network that encodes the absolute value of simultaneous and successive luminance contrast.

◆ **Speed of processing in a go/no-go visual categorisation: low *versus* high stimulus complexity**

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Using ERPs, we showed that the human visual system can process natural images in 150 ms [Thorpe et al 1996 *Nature (London)* **381** 520–522), and that processing time is probably shorter in monkeys (Fabre-Thorpe et al, 1998 *Neuroreport* **9** 303–308). In both studies subjects had to detect animals in briefly flashed (20–30 ms) previously unseen photographs, a task which presumably involves structures like the inferotemporal cortex. Would processing time be shorter for categorisations based on simple features? To test this idea, humans alternated between the animal-detection task and a simple squares versus circles paradigm. The simple stimuli were grey rectangles (same size as the photographs) with randomly positioned squares or circles of various grey levels. Accuracy was higher for the low-level task (97% vs 92%), but on average it took only 40 ms longer to detect an animal in a complex scene than to identify a square (497 ms vs 454 ms), and the earliest behavioural responses had about the same latency! Moreover, ERPs showed differences between target and non-targets starting around 150 ms in both cases. The processing overheads associated with complex image categorisation appear remarkably limited. For both simple and complex categorisation the underlying visual processing seems massively parallel and largely feed-forward.

◆ **VEPs to dichoptic presentation of gratings and noise**

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Earlier we showed the effect of white additive visual noise on the spatial-frequency characteristics of the main VEP components for monocular viewing (Shelepin et al, 1997 *Perception* **26** Supplement, 135). In this study, we used dichoptic stimulation and compared the VEPs with those obtained for monocular stimulation (both recorded from the occipital lobe). Sixteen observers viewed sinusoidal gratings with the right eye, while the visual noise was added via a mirror to the left eye. In the control experiment, visual noise was replaced with a uniform gray field. We used six spatial frequencies (0.4, 0.8, 1.6, 3.2, 6.4, 12.8 cycles deg^{-1}) and a temporal frequency of 1 Hz. In the presence of noise, the amplitude of early VEP components N1, P1, and the late positive component P2 decreased; only the late negative wave N2 increased for all spatial frequencies. The effect of noise on the amplitude of VEPs obtained for monocular and dichoptic stimulation was similar. Since in the dichoptic condition signal and noise can be intermixed only at the cortical level, it can be assumed that the external noise is filtered by the cortical neurons.

◆ **Timing of colour and motion processing in human visual cortex: an evoked visual potential study**

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We studied the timings of colour and motion processing and their interaction in the human visual system. Multichannel visual evoked potentials (VEPs) were recorded in 17 healthy, right-handed subjects presented with either stationary colour checkerboards, black-and-white motion gratings, or moving colour gratings with tritanopic displays. VEPs were analysed in terms of topographic scalp potential distributions (temporal segmentation) and underlying neuronal generators (source localisation). Results revealed several condition-specific potential distributions (maps) that could be grouped in early (40–75 ms) and late (175–240 ms) VEP responses. Both the early and late maps associated with motion processing occurred earlier than the corresponding maps reflecting colour processing (latency differences: 20–30 ms). Surprisingly, when motion was combined with colour, both early and late VEP maps occurred much earlier than those of motion or colour alone. Source localisation revealed several neuronal generators that seem to reflect a summation of those implicated in either colour or motion processing alone. Results suggest that, as reported for monkeys, the human motion system is faster than the colour system and indicate that the colour system may contribute directly to the analysis of motion, through an interaction between the different subcomponents of the visual system implicated in motion and colour processing.

◆ **No evidence of parvocellular involvement to chromatic motion VEPs**

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VEPs to motion-onset achromatic and red/green isoluminous gratings were obtained. The stimuli used were sinusoidal gratings with a spatial frequency of 1 cycle deg^{-1} which drifted horizontally at a rate of 4.5 deg s^{-1} or 5.6 deg s^{-1}. The stimuli were presented with a duty cycle of 10%, motion for 100 ms (onset) followed by a stationary period of 900 ms (offset)—a duty cycle of 10%. The contrast was changed from 0.8% to 50% in twelve steps. Chromatic motion-VEPs are of smaller amplitude and longer latency than achromatic motion-VEPs. No major differences were seen in the shape of the contrast functions obtained for chromatic versus achromatic motion-VEPs. However, the contrast response functions of the chromatic and achromatic motion VEPs are similar, except that the chromatic N2 component's function has been shifted by approximately $\frac{1}{2}$log unit in contrast. This could be interpreted as the chromatic contrast being only 30% as effective as achromatic contrast. One must assume that the similarities of the contrast functions reflect activation of similar neurons for chromatic and achromatic motion. These results may be consistent with red/green contributing to the magno system responding to motion. The motion channel is likely to be colour-blind in the sense that it does not use information about colour per se, nor does it process colour information veridically.

SPACE, SHAPE, AND DEPTH

◆ **The role of spatial derivatives in visual coding of edges**

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Our previous psychophysical work supports the use of local derivatives of luminance for locating edges in human vision, but does not distinguish between locating edges at a peak in the (smoothed) gradient magnitude (1st derivative) or at zero-crossings (ZCs) in the 2nd derivative. We presented stimuli that consisted of a uniform ramp of luminance (ie constant gradient) with a localised region of gradient change either added to or subtracted from the ramp. This localised gradient increment or decrement always gives a ZC in the 2nd derivative, and corresponds to a gradient maximum for increments but a gradient minimum for decrements. The threshold for detecting a gradient change was nearly constant, irrespective of the background gradient. This insensitivity to the background gradient is more consistent with detection based on a 2nd derivative representation than one based on the 1st derivative. However, we also found that subjects could reliably distinguish between increments and decrements of gradient change near threshold. Increments were classified as a single edge while the decrements contained multiple features, even though the shapes of their 2nd (and higher) derivatives are the same. Thus analysis of spatial structure cannot be based on the 2nd (or higher) derivatives alone.

◆ **Integration of oriented contours across space: specificity for luminance and contrast modulation**

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Evidence from detection tasks suggests that luminance-modulated (LM) and contrast-modulated (CM) gratings are analysed separately in human vision. Here we ask whether the two types of information are combined to improve performance in orientation discrimination. When LM and CM were spatially superimposed, we found no improvement compared with LM or CM alone. We now consider the integration of contour information across space, using spatially separated gratings. Stimuli consisted of one or two small patches of LM or CM grating (2 cycles deg^{-1}, 0.75 deg diameter) presented at 4 times detection threshold, in a static binary noise field. Orientation discrimination thresholds were measured by 2AFC methods for single patches and patch pairs (LM/LM, CM/CM, LM/CM). Considerable improvements in orientation discrimination for two patches (compared with a single patch) occurred only when both patches were of the same type and the bars were globally aligned. For dissimilar (LM/CM) or misaligned patches, discrimination showed only modest improvements over a single patch. This suggests that integration of collinear subunits by higher-order 'collator' units occurs only for subunits of the same type, implying that subunits and collators are specific for LM or CM information.

◆ **Noise is good—stochastic resonance and vision**

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Stochastic resonance is a nonlinear cooperative effect whereby the response of a nonlinear system to a weak periodic stimulus is enhanced by the presence of an optimal level of input noise. In short, adding noise to a system can help in the detection of an otherwise invisible signal. The effect of two-dimensional static Gaussian white noise (RMS contrast 0–0.39) upon the contrast detection thresholds (CDTs) of one-dimensional stationary Gabor patches was measured. A two-temporal-interval, 2AFC signal detection paradigm was used. Noise was added to both intervals. The signal was displayed in one interval. Observers reported in which temporal interval the signal was present. CDTs were obtained for foveally presented Gabor signals of various spatial frequencies (1–8 cycles deg^{-1}), a 2 cycles deg^{-1} Gabor signal presented 2.8 deg above the point of fixation, and a 2 cycles deg^{-1} Gabor signal presented foveally for two durations (13 ms and 80 ms). Facilitation (lowered CDTs) occurred when noise (up to approximately 0.15 RMS) was added to the signal. Masking occurred for greater noise amplitudes. Facilitation was greatest for 2 cycles deg^{-1} Gabors (eg 0.08 RMS noise lowered the CDT by a factor of $\sqrt{2}$ compared to no-noise baseline). Facilitation occurred at both retinal locations and signal durations.

◆ **A quantitative model for perception of structure in stationary plaids**

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Superimposed sine-wave gratings with spatial frequency (SF) of 1*F* and orientations of ±45° fuse perceptually to look like a blurred checkerboard. Previous work found that fusion is broken when 3*F* components are added in square-wave phase but that it is enhanced by adapting to 3*F* components. These observations have prompted an image-processing model where filter combination is controlled by 3*F* filters. At each position in the image, a pair of oriented, quadrature-filters compute energy. Where local energy-peaks in orientation/SF space are found, the corresponding filters are termed (1*F*) anchor-filters. Energy at each anchor-filter is used to normalise energy in a similar filter at 3*F*. For each anchor-filter, a synthetic filter is created by summing even linear-filters at neighbouring orientations: the lower the normalised response of the 3*F* filter, the broader the extent of summation around orientation. These computations are repeated at each position in the image and features are marked by superimposing zero-bound regions in each synthetic filter. The model predicts several previously reported results. For example, for a plaid to segment, more harmonic contrast is required when either the phase of a third-harmonic is changed from square-wave to triangle-wave, or the harmonic SF is increased.

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◆ **Peripheral vision facilitates depth perception in the fovea**

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The primary objective of this study was to investigate the interaction between foveal and peripheral vision. In particular, we report on the effect of peripheral vision on the depth judgments in the fovea. Subjects observed the 1.75 m display at a distance of 1 m, and they judged the depth order of a pair of two dots (standard and target) which simultaneously appeared around the centre of the display. The horizontal disparity of two dots was randomly selected by the fixed step and the dots were repeatedly displayed. When subjects observed these test stimuli, three viewing conditions were employed. (i) Approximately one thousand dots with individual horizontal disparity were randomly allocated at the peripheral area, and were moving toward the subjects. (ii) Peripheral dots appeared but were stationary. (iii) No peripheral dots appeared. We compared the results of judgments under the three conditions as a difference of judgment ratio, at which subjects judged the target point as being nearer than the standard point. The probit analysis was applied to the data of judgment ratio, and the results suggest that subjects' performance was rather sensitive when peripheral information was displayed. The effect of motion of the peripheral dots, however, was not clear.

◆ **When is a rectangle not a square? A viewpoint-sensitive visual discrimination**

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For an active observer, using vision effectively includes knowing how to arrange informative viewpoints. Studying that skill requires tasks which are sensitive to viewpoint selection. We have examined two variants of one such task, which is judging whether rectangles resting on a horizontal surface are square. In the 'large-scale' study, stimuli (resting on the floor) had dimensions of 10 cm × 10 cm, 10.2 cm × 9.8 cm, and 10.4 cm × 9.6 cm. Subjects judged from a distance of 4 m,

then moved closer by 0.5 m for successive judgments until they were 1 m away. Although confidence rose steadily, accuracy was low, and improved only for the intermediate stimulus. In the 'small-scale' study, subjects viewed rectangles of 4 cm × 4 cm, 4.1 cm × 3.9 cm, and 4.2 cm × 3.8 cm (on a table top, inclined at about 45° by 'handles' projecting from the back) from about 1 m. Viewpoint was varied by rotating objects through four 45° steps about a vertical axis, ending with the surface almost orthogonal to the line of sight. Both confidence and accuracy peaked in the final position. Monocular viewing gave greater accuracy than binocular. These findings set the scene to ask whether subjects who are free to select their own viewpoint take effective account of the abilities and limitations demonstrated here.

◆ **Laparoscopic performance is predicted by a test of pictorial perception: Three replications,**
A135 **using novices and experienced surgeons**

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Laparoscopic ('keyhole') surgery depends on recovering the shape of 3-D structures such as a patient's internal anatomy from 2-D displays on a video monitor. Differences in aptitude for that task are potentially critical for surgeon selection and training, and the issue has become more pressing with evidence that commercial 3-D camera systems do not compensate for the loss of depth information. In a series of three studies we investigated the relationship between laparoscopic ability and aptitude for recovering depth information from 2-D monitor displays. Participants completed a cutting task that simulates laparoscopy, and PicSOr, a test which measures perception of depicted surfaces by techniques developed by Cowie (1998 *Perception* **27** 505 – 540). In studies 1 ($n = 32$) and 2 ($n = 48$) participants were laparoscopic novices: in study 3 ($n = 32$) 16 of the participants were experienced laparoscopic surgeons. All three studies showed that PicSOr consistently predicted performance on the cutting task: (study 1, $r = 0.5$, $p < 0.004$; study 2, $r = 0.497$, $p < 0.0003$ and study 3, $r = 0.417$, $p = 0.01$). Encouragingly, it was also significantly correlated with surgical operative experience ($r = 0.343$, $p = 0.05$). PicSOr is the first psychometric task to predict laparoscopic performance reliably.

◆ **Luminance contrast rivalry and texture appearance**
A136

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Luminance disparities in the two retinal projections elicit rivalry phenomena which are used as a depth cue [Howard and Rogers, 1995, in *Binocular Vision and Stereopsis* (Oxford: Oxford University Press) pp 235 – 312]. We studied the effect of luminance contrast disparities on the perception of a textured surface. The binocular stimuli consisted of two arrays of grey elements randomly chosen within a grey scale. Two types of stimuli were constructed: a reference stimulus with the luminance of the corresponding elements being 100% correlated, and a test stimulus with the luminance of the corresponding elements being 100% anticorrelated. Average luminance remained constant as the contrast of the elements varied. We investigated (i) the texture discrimination threshold when the observer was presented with a reference stimulus and a test stimulus, using a 2AFC procedure; (ii) the texture identification threshold using a yes/no procedure. The observer had to report on a depth cue. The results show that luminance contrast is higher for texture identification than for texture detection (0.042 versus 0.031 for one observer). The three observers reported that they were faced with several indices: absence of flatness appearance, increased brightness, or depth cue. The question arises whether discrimination and identification thresholds could respectively result from the effect of binocular summation and the effect of luminance rivalry.

◆ **How many channels determine the RT to grating onset detection?**
A137

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It is known that RT to grating onset detection increases as stimulus spatial frequency (SF) increases. This is interpreted as the result of the operations of two channels with different temporal properties in the visual system. In the present work, the number of underlying mechanisms was evaluated by considering the effect of SF uncertainty on RT. It was found that SF uncertainty increased RT for low-contrast gratings (suggesting two underlying mechanisms). At a higher contrast, SF uncertainty did not increase the RT (suggesting one underlying mechanism). The type of the underlying mechanisms (transient or sustained) was evaluated by the effect of the duration of the gradual onset of the stimulus on RT. An increase of onset duration

(0–60 ms) at low SFs substantially delayed RT for all contrasts employed. Conversely, at high SFs this effect was present only for gratings with a high contrast. These results suggest that RT is determined by two mechanisms (transient and sustained) at a near-threshold contrast, and by one (transient) mechanism at higher contrasts.
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◆ **Spatial-frequency discrimination of separated Gabor patches**

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How do we compare the properties of visual stimuli that are separated by many degrees of arc? In studying this issue, one problem is that the subject may develop an internal standard, or a template, representing the average stimulus over many trials and may make an absolute judgment, comparing the external test stimulus to the internal standard rather than to the external referent. Lages and Treisman (1998 *Vision Research* **38** 557–572) suggested this is why subjects are able to discriminate spatial frequencies when the two stimuli are separated in time by many seconds or minutes. To avoid this strategy in the spatial case, we have measured spatial-frequency discrimination thresholds for Gabor patches with 25 randomly interleaved referent stimuli. The referent stimuli were narrowly spaced in frequency between 1.76 and 2.24 cycles deg^{-1}. On any given trial the target differed from the current referent by a certain factor, and this factor was adjusted according to a staircase procedure. The test and referent stimuli were two Gabor patches, which always lay on an imaginary circle of 5 deg radius. Performance was as good when two stimuli were separated by 10 deg as when the two Gabors were juxtaposed.

◆ **Spatial-frequency processing delays and temporal-order judgments**

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There is a great deal of evidence which suggests that there are differential delays involved in the processing of spatial frequencies such that lower spatial frequencies are processed faster than higher ones. The nature of these spatial-frequency processing delays was examined by means of temporal-order judgments, that is subjects indicated which of two visual events presented at different times occurred first. In both experiments reported here, equally detectable 0.5 and 16 cycles deg^{-1} Gabor patches were presented centrally at a variety of stimulus onset asynchronies. In the first experiment subjects indicated their temporal-order judgment after a single presentation, while in the second experiment the presentation order was cycled until the subjects made a decision. The results were fitted with a probit curve and it was found in both experiments that the point of simultaneous onset was not significantly different from zero. Overall, the results show no evidence for spatial-frequency processing delays of the magnitude predicted from reaction time and VEP experiments. Indeed, the results show no support for spatial-frequency processing delays at all, as the points of simultaneity found do not significantly differ from the point of physical simultaneity.

◆ **The effect of spatial frequency on visual discrimination of texture**

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The hypothesis that texture-discrimination RTs depend on spatial-frequency modulation was evaluated. We hypothesised that texture-identification and texture-discrimination RTs increase as spatial frequency increases. In this study spatial-frequency modulation was measured in terms of the amount of information, ie the length of computer encoding. Five spatial-frequency ranges were used. For each of them, pairs of textures were generated. In 'same' trials, two identical textures were displayed simultaneously; in 'different' trials, one texture was altered by using a JPEG technique. Same/different data support our hypothesis and show that spatial-frequency modulation is a good predictor of texture-discrimination RTs. The higher the spatial frequency, the longer the RTs.

◆ **Disappearing tricks: How the area of surrounding texture affects perceptual fading**

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A peripherally presented grey target embedded within a dynamic random-noise surround will perceptually fade after ~10 s of fixation. We are interested in the processing underlying this phenomenon and the extent to which long-range interactions are involved. For a target sized 2.25 deg^2, we varied the area of surrounding texture from 3 to 130 deg^2 to explore how time-to-fade

is affected for two types of target patch: one differed from the surround in texture, the other in motion coherence. We found that time-to-fade increased as the area of surrounding texture increased; ie a small surround produced faster fading than a surround that was a full screen of texture. Times-to-fade for motion-defined and texture-defined patches differed in magnitude but produced similar functions. It appears surprising that faster fading occurs for a smaller surround as it might be supposed that only local interactions at texture borders are critical in effecting fading. On this hypothesis, once there is sufficient texture, increasing the texture quantity further will have no effect on time-to-fade. However, we did not find this (but see De Weerd et al, 1998 *Vision Research* **38** 2721 – 2734) and suggest that the mechanisms responsible for fading involve longer-range interactions, and are thus spatially extensive.

◆ **The role of empty space in coding relative positions**

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We are trying to take a new perspective on the issue of how visual space is represented. Specifically, it is proposed that relative positions of objects might be partially coded by the amount of empty space between them. To test this hypothesis, we have explored whether perceptual space could be induced to expand or contract by stationary moving stimuli (a moving sinusoidal enveloped by a stationary Gaussian window) and, thus, alter the observer's judgment about the relative positions of objects. Three experiments were conducted to address the following issues: (1) Can the reported apparent position shifts of stationary moving Gabors be accounted for by the imbalance of empty space surrounding them? (2) Can we apply the same theory to explain other visual phenomena? (3) Do other theories give the same or better predictions? Our results indicate that: (i) The apparent position shift of a stationary moving Gabor can be accounted for by the asymmetry of tensions of the visual space on the two sides of the Gabor along its component motion axis. (ii) Local visual space distortions affect one's relative position judgments on the neighbouring neutral markers. (iii) No other simple explanations that we know of could account for the results.

◆ **Large systematic deviations in a visual parallelity task**

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If visual space is curved, as Luneburg suggested, subjects will not see two parallel bars as parallel but as bars which are at some angle. In our experiment we used this prediction to determine the deformation of visual space. In a binocular task the subjects had to set a test bar parallel to a reference bar placed in a horizontal plane at eye height. The reference and test bars were always placed at the same distance from the subject and such that the separation angle varied from 0° to 60° in steps of 15°. The distances used were 1.47 m, 2.1 m, and 4.31 m. The size of the bars was scaled with distance. A chin-rest was used so that only eye movements were possible. The orientation of the reference bar was varied in steps of 30°. The results indicate that the deviation between the orientation of the test and reference pointers increased as the separation increased. At a close range (1.47 m) subjects tended to be more veridical. Interestingly, the deviation depends on the actual reference direction with deviations up to 30° for oblique angles. Such an oblique effect cannot be predicted by a Riemannian metric as proposed by Luneburg or by any metric.

◆ **Recognition of narrow-pass filtered figures with complete and incomplete contours**

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It is well established that pattern recognition is related to the spatial-frequency spectrum of the stimulus image. The aim of the present work was to measure visual performance for recognition of figures generated by means of discrete elements. Every discrete element was filtered so as to provide only a narrow spatial-frequency range. In these circumstances, it was found that recognition of incomplete figures improves for high-pass bands and for element sizes greater than 3 min of arc. We established also the optimal recognition distances of optotypes with a contour defined by a sinusoidally shaped luminance profile. This new test can be used for clinical purposes.

◆ **Influence of setting on shape perception**

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Normally objects occur in an environment. This is important because the context in which an object appears affects its visual shape. This study is an investigation of the effects of scene geometry and viewing conditions on the perception of shape. Stimuli for this investigation are either actual 3-D scenes or photographs of 3-D scenes. The scenes consist of triaxial ellipsoids lying on a table, against a distant backdrop. Objects are finished matte white, approximating Lambertian diffuse reflection. Visual shape is quantified via a probe for surface attitude: a gauge figure has to be adjusted such that it appears as a circle painted upon the surface of the objects (Koenderink et al, 1996 *Perception & Psychophysics* **58** 163–173). In this way we sample slant and tilt at many locations. Setting and field of view are varied parametrically. Detailed quantitative results of the influence of the setting have been gathered for size, distance, and orientation (relative to the observer) variations. The influence of the field of view is being studied in detail by manipulating size, position, and form of frames in relation to observer and scene. Overestimation of relief by a factor of 2–4 occurs, depending on details of setting.

◆ **Haptic feedback affects visual perception of surfaces**

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To derive an estimate of surface slant, the visual system combines information from several cues, each weighted according to its reliability. We asked whether the weights change after providing haptic feedback consistent with one cue only. During the feedback phase of the experiment, subjects pushed a cube across various planes. The cube and the planes were seen and felt. Visually the plane had texture and disparity gradients specifying different slants. Haptic sensations for the cube and plane were provided with a force-feedback device (PHANToM); the haptic feedback for the plane was consistent with its texture gradient only. Before and after the feedback phase, subjects made slant settings (without haptic feedback) from which we determined the weights assigned to texture and disparity. The texture weight increased significantly from 25% to 38%. We also conducted two control experiments that showed that the change in weight does not occur over time without the texture–disparity conflict and that the weight change was not caused by visual experience alone. We conclude that giving haptic feedback consistent with one cue causes its weight to increase in a purely visual task. Thus, haptic feedback affects visual surface perception. Calibration of the visual system is affected by visuomotor interaction.

◆ **Accuracy of slope perception affected by the psychophysical method**

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Several methods are in use to assess the accuracy of judgments of surface inclination. Proffitt et al (1995 *Psychonomic Bulletin and Review* **2** 409–428) reported that the method of adjustment (with a 'paddle') led to veridical judgments of slopes. In contrast, verbal magnitude and visual adjustment tasks led to overestimations. These findings can be interpreted in terms of a difference between action-based responses which are veridical, and visual/verbal judgments which overestimate slope. Here we report a comparison of different psychophysical methods used to assess the accuracy of judgments of photographic slopes. The methods used have been previously reported. Experiment 1 ($N = 18$) showed that the paddle method led to more accurate judgments than verbal magnitude judgments. Observers could see the paddle while adjusting it, and thus it is possible that the response was based on haptic and visual information. In experiment 2 four conditions were compared ($n = 4 \times 10$): (i) paddle matching–paddle seen, (ii) the same, but paddle hidden, (iii) verbal judgments, (iv) visual judgments. The results support the view that action-based responses are more accurate than visual and verbal judgments. The implications for slope perception in pictures are discussed.

◆ **Qualitative curvature cues in viewpoint-invariant recognition of bent pins**

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The curvature at a point in the retinal image of an object varies with viewpoint, but the type of curvature (positive, negative, zero) relative to the object does not. To test whether such qualitative

cues can be used in same–different judgments about simple depth-rotated objects, observers were presented with brief computer-generated images of two bent pins viewed from different directions. Each bent pin comprised two abutting arms, one straight, the other with constant curvature towards or away from the other arm, the amount varying between trials. Each arm was 35.0 mm long and 3.5 mm wide when viewed at 2 m. Images were realistically rendered with no perspective cues. In half the trials, the two images were of the same bent pin viewed from different directions; in the other half, the two images were of differently curved bent pins viewed from different directions. Discrimination was poor when the arms of the pins were both curved in the same direction and best when they were curved in opposite directions or when just one arm was curved. Observers may use qualitative curvature cues to achieve fast, viewpoint-invariant recognition of simple objects.

◆ **The influence of highlights on pictorial shape**

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It is a well known trick among painters to paint a highlight in the iris of an eye. This instantly changes the pictorial shape of the eye from a flat disc to a round ball. So somehow highlights influence pictorial shape. Most of the literature on shape-from-highlights has focused on establishing that there is indeed such an influence, but yet little is (scientifically) known on what this influence is. We investigated the influence of highlights on pictorial shape by parametrically varying the amount of gloss of an otherwise matte object. To do this we used two objects with exactly the same shape. One object was painted matte, the other was covered with a metallic coating, so that the surface became mirror-like. Photographs of the two objects were linearly combined to vary the gloss of the stimuli. We used the gauge-figure task as described by Koenderink et al (1992 *Perception & Psychophysics* **52** 487–496) to study pictorial shape. Initial results indicate that highlights cause systematic shape deformations.

WEDNESDAY and THURSDAY

POSTERS B

EYE MOVEMENTS

◆ **Measuring saccade velocity with a dual-colour LED flicker**

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I developed a novel method for measuring saccade velocity. When a tiny flickering radiant is displayed during a saccade (in a dark room), a row of radiants is 'painted' onto the eye (a phenomenon known as visual persistence). Since the spatial interval between the perceived neighbouring radiants is relative to the speed of the eye, saccade velocity can be calculated from that interval. Here, the radiant consisted of a dual-colour LED, flickering on and off, with red and green occurring alternately. The size of the radiant was adjusted by means of an electrical shutter. The viewer looked at two fixed targets, alternately, with one eye; the flickering radiant was then displayed on the saccade trajectory. To the viewer, the image appeared as a row of red and green radiants. While the viewer perceived gaps between the radiants when the size of the radiant was small, the combination colour, yellow, was perceived when the size was large. Saccade velocity was calculated from the size that just closed the gap between the perceived radiants. This method is especially advantageous for clinical tests; it is simple, secure, and accurate even for vertical saccades.

◆ **Temporal location of colliding objects more accurately perceived during smooth eye pursuit**

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In the Aubert–Fleischl phenomenon (AFP), a moving object appears slower when pursued. Some authors therefore conclude that extra-retinal signals underestimate eye speed. This predicts that judging the temporal location of object collision should be less accurate during pursuit. To test this, we had observers estimate the collision time of two objects using a mouse-press. Displays depicted a stationary obstacle and moving target, both disappearing 1500 ms before collision. In the pursuit condition, observers pursued the target with an eye movement. In the no-pursuit condition, observers fixated the obstacle. The obstacle flashed for 10 ms at a rate of 2 Hz to reduce the salience of its retinal motion during pursuit. Temporal location was estimated more accurately during pursuit. Experiment 2 revealed a weak but reliable AFP for these stimuli. Experiment 3 compared 'flash' and 'no flash' conditions, the latter depicting a continuously visible obstacle that disappeared after the observer made his/her judgment. ANOVA revealed significant main effects for type of pursuit and obstacle, but no interaction. Pursuit produced more accurate judgments of temporal location, regardless of obstacle type. Extra-retinal signals may therefore encode object speed more accurately. If so, the AFP arises from retinal signals that overestimate object speed.

◆ **Localisations at the beginning of linear and circular movements**

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When observers are asked to determine the point at which a linear moving stimulus enters a window, they typically do not localise the stimulus at the window's edge, but rather at a later position within the window (Fröhlich effect). We (Müsseler and Aschersleben, 1998 *Perception & Psychophysics* **60** 683–695; Aschersleben and Müsseler, in press *Journal of Experimental Psychology: Human Perception and Performance*) explained this phenomenon within an attentional framework. The basic assumption is that the entrance of the stimulus into the window initiates a shift of attention. While this shift is under way, the stimulus moves into the window. Since the first phenomenal representation of the stimulus is not available until the completion of the attention shift, the stimulus is perceived at a later position within the window. To date, evidence supporting this view has been derived from studies based on linear movements. In recent experiments with circular movements, the effect disappeared. This implies that the attention shifts responsible for the Fröhlich effect are yoked to the planning of saccadic eye movements, for circular target movements afford no such planning. This claim is further supported by the finding that experimental manipulations designed to allow saccadic planning resulted in a reappearance of the Fröhlich effect with circular movements.

◆ **Dynamic visual perception and daily practice in dyslexia**

B004 F Burkhart, K Hartnegg (Institute of Biophysics, University of Freiburg, Hansastrasse 9a, D 79104 Freiburg, Germany; fax: +49 761/203 9540; e-mail: bfischer@uni-freiburg.de)

A magnocellular deficit in dyslexia is suggested by brain imaging [Eden et al, 1998 *Nature (London)* **382** 66–69] and psychophysics (Lovegrove, 1993 *Annals of the New York Academy of Sciences* **682** 57–59). A deficit in antisaccade generation has been reported (Biscaldi et al, 1998 *Neuropsychologia* **36** 1189–1202). We tested dynamic vision of 344 dyslexic and 127 control children by three perceptual tasks requiring steady fixation (1), saccades (2), and saccades against a distractor (3). In each task, the last orientation of a small quickly changing pattern was signaled by a key press to measure the percentage of correct responses. Performance in these tasks was compared with error rate in an antisaccade task. Saccade control of 70 dyslexic children was retested after daily training with visual tasks. We observed age-dependent group differences (maximum 25% at age 9–10 years). The fraction of dyslexics performing worse than 84% of the controls varied from 27% to 61%. 70 dyslexic children with saccade control deficits were given daily practice (3 to 6 weeks, 10 min day^{-1}). They significantly improved their perceptual and voluntary saccade performance. Both deficits may be a consequence of deficits in the m-system projecting to corresponding cortical areas. A test of saccade and dynamic visual perceptual performance followed by daily practice may be helpful for dyslexics.

◆ **The Z-illusion: significance of eye movements in geometrical illusions**

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In the Z-illusion, the upper/lower short line of a big serif letter Z does not seem to line up with the lower/upper corner. The illusion disappears after prolonged fixation. Some geometrical illusions are stable; others disappear with fixation. The Poggendorff and the Gerbino illusions may be related to the Z-illusion and both disappear with fixation. The Giovanelli illusion is different but disappears as well. To study the Z-illusion we measured the apparent deviation z as a function of height h. A plot of z vs h reveals an almost linear relationship, with an intercept different from zero. This is not predicted if the illusion depends on a constant orientation mismatch. We also measured the fixation time T after which the Z-illusion disappears. T became shorter within the first 20 trials and varied considerably depending on the observer: 6–10 s at the beginning; 2–4 s at the end. When repeated after 4 or 24 hours parts of the training effects were reset. It is not yet fully understood why only some illusions disappear with fixation.

◆ **Spatiotemporal properties of saccades elicited by two-dimensional target position**

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The spatial nonuniformity of saccadic properties was studied in macaque monkeys by measuring eye position with a magnetic search coil. Monkeys were trained to perform visually guided saccades by being required to detect the dimming of a small target (0.2 deg in size). The gap–overlap paradigm was used to elicit the saccades in single-step trials. Saccades were made from a central fixation point to a peripheral target at one of 34 possible locations ($-19.5/+19.5$ deg on the horizontal axes and $-13/+13$ deg on the vertical axis, at 6.5 deg spacing on both axes). The dependence of reaction time to visually guided, and the amplitudes of corrective and anticipatory saccades on peripheral target position was analysed. The results revealed the presence of focuses of short-latency and long-latency saccades. These focuses were asymmetrically positioned in the visual field along both horizontal and vertical axes. The direction and amplitude of anticipatory saccades were asymmetrically distributed on the visual-field plane. It was shown that there are zones of more or less precise formation of visually-guided saccades. The present results point to the existence of a complicated asymmetry of oculomotor reactions in the visual field.

◆ **Pure efference-copy-driven smooth pursuit**

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The canonical efference-copy model of smooth-pursuit eye tracking implies the possibility of pure efference-copy-driven smooth pursuit, ie smooth eye tracking in the absence of any physical movement relative to the retinal frame of reference. This prediction was tested in an experiment involving attempts to initiate and sustain ocular pursuit over an empty screen. Twelve participants took part in this experiment. Eight were first trained to elicit sigma smooth pursuit, then, to produce solid-line

smooth pursuit (Lamontagne et al, 1993 *Perception* **22** 477–482), and, finally, to initiate smooth pursuit over a homogenous screen. The other four participants could already produce smooth pursuit in these three conditions. The experimental session ran for 5 min; participants were asked to attempt to initiate smooth pursuit over an empty screen as many times as possible. Eye movements were documented by EOG. All participants succeeded in producing smooth pursuit over an empty screen (up to a maximum of 20 successful attempts), and all reported experiencing movement during smooth pursuit.

◆ **Eye fixation points and landscape choice**

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This study was conducted in order to investigate if it is possible to establish some kind of relation between landscape preferences and the parts on the landscapes the subjects fixate with their eyes. Fifteen slides with pairs of photographed real scenery were presented to the subjects. Each pair represented two opposed characteristics of one bipolar dimension (humanised vs unchanged landscape, rounded and diffused vs straight and sharp shapes, and hard vs soft landscape). The task was to look at the two landscapes in the slide and to show preference for one of these while eye movements and ocular fixation points were recorded with a NAC EMR 600. Results showed that, on average, there were more eye fixations in the preferred than in the non-preferred landscape, and, what is more interesting, the subjects who preferred humanised landscape had fixed their eyes specifically on houses and other human constructions, while the subjects who chose the unchanged landscape seemed not to notice those parts.

◆ **The functional structure of the smooth-pursuit system**

B009 P Bruno, P Inchingolo¶ (Department of Psychology, University of Trieste, via dell'Università 7, I 34123 Trieste, Italy; ¶ Department of Electrical Engineering, Electronics, and Informatics, University of Trieste, piazzale Europa 1, I 34127 Trieste, Italy; fax: +39 040 31 2272; e-mail: bruno@gnbts.univ.trieste.it)

The smooth-pursuit eye movements originate from a subsystem (SPS) of the oculomotor neural control system. Smooth pursuit is a visually guided movement; however, it depends also on perception and cognition. The basic scheme of the SPS is a velocity servo, which cooperates with a position controller provided for visual tracking by the ocular saccadic system. The neuronal substrate for the SPS involves many cortical and subcortical areas that exhibit dynamic differences and also differences in sensitivity. The visual input subserves several transformations that determine a different informational content of the neural signal at different stages of the processing. We propose a scheme which describes the transformation of the visual input throughout the system from retina to the eye muscles. We assign a functional meaning to a distributed and parallel organisation of cortical and subcortical areas as well as to a modular organisation, with a crucial role for cross-inhibition. We propose that such organisation is functional to a visuomotor transformation from retinotopic to muscolinic coordinates. The model can reproduce most of the eye-tracking alterations found in lesion and electrical-stimulation experiments and may be a valuable tool for comprehension of interaction between perception and motion.

◆ **Different effects of a secondary task on saccades and anti-saccades**

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It is unclear when and how attention affects saccade performance. We examined the effects of a concurrent perceptual discrimination task on saccade and anti-saccade performance. Our observers made saccades to a horizontally displaced fixation point, while concurrently judging which of two sinusoidal gratings appearing above and below the fixation point was of higher spatial frequency. Observers also performed anti-saccades of similar amplitude in the opposite direction. The SOA between the two tasks ranged from −200 to 400 ms. When observers performed both tasks, latencies of regular saccades were increased if the grating appeared 100 ms before, or simultaneously with, the saccade target. A grating that appeared after the fixation displacement had no effect on saccadic latency. Anti-saccadic latency was, on the other hand, reduced when the grating appeared 100 to 200 ms before the fixation displacement, but unaffected when the grating appeared simultaneously with, or right after, the displacement. Our results suggest a transient demand for attention by the preparation of saccades. That the secondary task has a different effect on saccades and anti-saccades is surprising, and is not explained by current conceptions of the relationship between saccades and attention.

◆ **Human saccades in search: second chances are worth a second peak**

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Previous studies have shown that the first saccade during search is guided by visual information about target location. Our current goal is to relate the amount of information used by the first and second saccades. Specifically, we compare the accuracy of the second saccade to that of an ideal observer forced to rely only on the information used by the first saccade. Three observers searched for a bright disk in white noise in one of ten locations along the circumference of a circle. A 'closest distance criterion' was used to define the decision accuracy of the first saccade, and of the second saccade given the first missed the target. Our ideal observer computes the likelihood of the target being at each location and sequentially directs its saccades in decreasing order of likelihood. To constrain our ideal observer to first-saccade information, internal noise was added to match the accuracy of the model and human first saccades. Human performance on the second saccade exceeds that of our ideal observer: 0.496 vs 0.374, 0.391 vs 0.267, and 0.694 vs 0.258, for the three observers. We conclude that second search saccades appear to have access to information acquired after the first saccade.

FACES

◆ **The abnormal looking behaviour toward upright and upside–down faces in autistic children**

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Autism is a rare but severe psychiatric disorder. It has been suggested that autistic children are unable to process facial information correctly, which has been supported by psychological experiments. In recognising upright faces autistic children performed worse, but in recognising upside–down faces they performed equal to or even better than normal children (Langdell, 1978 *Journal of Child Psychology and Psychiatry and Allied Disciplines* **19** 255–268; Tantam et al, 1989 *Journal of Child Psychology and Psychiatry* **30** 623–630). The suggestion by Langdell that the looking behaviour of autistic children differs from that of normal children was tested. Our results showed that normal children spent more time looking at upright and less time looking at upside–down faces, whereas the autistic children did not differ between the two orientations. This difference in scanning time might be related to the aforementioned differences in performance between autistic and normal children for recognising upright and upside–down faces. Autistic children would rely less on the natural configuration of the facial elements, and their performance and looking behaviour would be less influenced by the distortion of this configuration, whereas the face-processing and looking behaviour of normal children are hampered by the inversion.

◆ **Perception of facial shape in foveal and peripheral vision**

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The purpose of the study was to compare the accuracy of facial-shape perception in foveal and peripheral vision. The stimuli were synthetic faces of photographic quality. Face shape was controlled by using dense correspondence maps describing the correspondence points between six basic faces. The shape dissimilarity of the six faces could be reduced by computing different mixtures of the correspondence map of each face and the mean of all correspondence maps. Dissimilarity thresholds were determined by using a 6AFC method. At each trial, the observer indicated which basic face had the best resemblance to the stimulus shown. Shape dissimilarity thresholds, expressed in the Euclidean distances between correspondence maps, were measured as a function of image size at the fovea and at an eccentricity of 10 deg in the horizontal meridian. At both eccentricities, dissimilarity thresholds decreased with increasing stimulus size. When the size of peripheral stimuli was scaled according to the cortical magnification factor (Virsu and Hari, 1996 *Vision Research* **36** 2971–2977), the foveal and peripheral performances were equal. The results suggest that shape perception of high-contrast facial images obeys the cortical-magnification theory.

◆ **Recognition of orientation-filtered facial expressions**

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Examples of six different facial expressions (happiness, sadness, anger, fear, disgust, surprise) posed by a number of different models from Ekman and Friesen [1976 *Pictures of Facial Affect* (Palo Alto, CA: Consulting Psychologists Press)] were filtered with Gabor filters. The filters were set at six different orientations (0°–horizontal, 30°, 60°, 90°–vertical, 120°, and 150°) for each of four bandpass spatial frequencies (24 different filters in all). In the first experiment, subjects were asked to identify the facial expressions shown in the filtered images. The results showed that recognition rates got progressively worse from the horizontal through to the vertical filters. In the second experiment, subjects were first trained to identify a number of the Ekman and Friesen models' faces (in unfiltered format). They were then asked to identify the same models when the faces were filtered with the 24 filters described above. The results showed a different pattern to that found for facial expressions: horizontal and vertical filters produced equally poor performance, and the filters lying between these two extremes produced the best recognition rates. These results have implications for the front-end processing of facial expression and facial identity.

◆ **Mechanisms of visual working memory in monkeys: influence of cortical location of APV**

B015 **administration on the effect of modification of cortical glutamatergic structures**

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NMDA-ergic structures in the visual (area 17) or prefrontal (area 46) cortex of rhesus monkeys were modified by perfusion of the NMDA antagonist—aminophosphonovaleriac acid (APV). We studied the effect of the modification on the characteristics of visual working memory and on the responses of visual and prefrontal cortical neurons which were simultaneously recorded. A combination of the microdialysis technique and multichannel recordings from single cortical units was used while each monkey performed a delayed visual discrimination task with coloured stimuli. APV administration resulted in a reduction of duration of short-term retention of information in the working memory with a reliable increase of motor reaction time. This impairment of working memory characteristics depended on the cortical location of APV administration. Administration of APV to area 17 resulted in more pronounced impairment and neuronal activity changes were found in both cortical regions. After treatment with APV of the prefrontal cortex, modification of neuronal activity was recorded only in the prefrontal cortex. Furthermore, the impairment of working memory was accompanied by a desynchronisation of neural activity, reflected in cross-correlation coefficients between simultaneous responses from neurons in different cortical regions. The results indicate a difference in the functional and structural organisation of glutamatergic structures in the visual and prefrontal cortex involved in the mechanisms of working memory.

◆ **The McGurk effect with upside–down faces**

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There is much evidence to show that face perception is reduced when faces are presented upside–down. I repeated the original McGurk experiment [McGurk and MacDonald, 1976 *Nature (London)* **264** 746–748)] using upright and inverted face stimuli, on 102 subjects. The original result was confirmed in both the upright and inverted faces. When vision and audition were inconsistent (ie vision is GaGa and audition is BaBa) most people reported the fused response DaDa. The upside–down face gave slightly more auditory responses (ie BaBa) and slightly fewer fused responses (ie DaDa). It would appear that the dynamic visual cues for lip-reading are vertically symmetrical, whereas the static cues for facial expression are asymmetrical—as in Thompson (1980 *Perception* **9** 482–484). These results are consistent with those of Green (1994 *Journal of the Acoustical Society of America* **95** 3014) and Jordan and Bevan (1997 *Journal of Experimental Psychology: Human Perception and Performance* **23** 388–403). Retinotopic and gravity cues are discussed.

◆ **Top–down and bottom–up processes in 3-D face perception: psychophysics**

B017 **and computational model**

T Papathomas, D DeCarlo (Laboratory of Vision Research, Rutgers University, 152 Frelinghuysen Road, Piscataway, NJ 08854-8020, USA: fax: +1 732 445 6715; e-mail: papathom@zeus.rutgers.edu; www: http://zeus.rutgers.edu/~/papathom)

A mask with its concave surface toward the observer appears as a normal face ('false percept'), under certain viewing conditions [Gregory, 1970 *The Intelligent Eye* (New York: McGraw-Hill)].

Moreover, if the mask is rotated, observers perceive it rotating in the opposite direction, if they maintain the false percept. We mounted a mask on a precisely controlled rotating platform, and we amplified the schema-driven, top–down influences by painting realistic faces on both (convex and concave) surfaces. We studied three data-driven processes for 3-D shape recovery that favour the veridical (hollow mask) percept: shape-from-motion; shape-from-binocular-disparity; and shape-from-shading (light from above). We investigated the influence of these bottom–up processes by determining the conditions that restore the veridical percept. In addition, we provided animated sequences of the rotating mask as input to a model-based algorithm [DeCarlo and Metaxas, 1998, in *Proceedings of IEEE Computer Vision and Pattern Recognition (CVPR) '96* pp 231–238] that incorporates the schema of a normal 3-D-face model to estimate the shape and motion of a face. The algorithm uses a combination of optical flow and edge information. The imposition of the schema causes the algorithm to detect opposite-direction motion, as humans do. Furthermore, there are interesting differences in estimating shape and speed between tracking a concave versus a convex painted mask.

◆ **Asymmetry of visual evoked potentials in the inferior temporal cortex and recognition**
B018 of facial expressions

E S Mikhailova (Department of Neurophysiology, Mental Health Research Center, 34 Kashirskoye Shosse, 115552 Moscow, Russia; e-mail: shevelev@lmnd.msk.ru)

Visual evoked potentials (VEPs) were used to study recognition of facial expressions and figures. With central stimulation, shorter latencies for N90 and P150 and larger amplitudes for P150 and N350 for expressive faces were found only in the right IT. Further, VEPs for faces exhibited significant hemispheric asymmetry—larger amplitudes of P150 and N350 in the right IT compared to the left one. In comparison, VEPs for figures revealed shorter latency for P150 in the left IT compared to the right one. Topographic maps of VEPs revealed the localisation of P150 in the right IT for faces, while figures elicited only slight activation in the left IT. Under stimulation of the left hemifield, significant enlargement of N90, P150, N180, and P250 waves was found in the right IT for expressive faces versus figures. Notably, dynamic mapping by VEPs for faces revealed the onset of activation in contralateral occipital cortex with fast successive activation of contralateral IT. The effect was parallel for the ipsilateral one; while for figures, only contralateral focus was found. The data suggest a principal role of the right IT cortex in the recognition of facial expression.

◆ **Recognition of facial identity between a child and an adult face**

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Three experiments were conducted to investigate whether we can recognise the facial identities, regardless of the structural changes of faces through growth from childhood to adulthood. In all experiments, pairs of child faces (5 years old) and adult faces (20 years old) were presented. Half of the pairs were faces of same persons (same-pairs) and the other half were faces of different persons (different-pairs). In different-pairs, a child face was combined with the adult face of a different person randomly. Observers were asked to rate facial identity on a 6-step scale (1 = maximum confidence that the two faces belong to different persons; 6 = maximum confidence that the two faces belong to the same person). In experiment 1 the mean rating score for same-pairs was significantly higher than the one for different-pairs. Experiment 2 showed that familiarity with adult faces improved recognition of the facial identity. Experiment 3 showed that recognition improved when both adult and child faces were judged distinctive. These results suggest that the face recognition system is responsive to facial changes through growth from childhood to adulthood.

◆ **Identification of human heads by using band pass filters**

B020 E Nakato, Y Nagata (Department of Psychology, Komazawa University, 1-23-1 Komazawa, Setagaya ku, Tokyo 154 8525, Japan; fax: +81 3 3418 9126; e-mail: enakato@komazawa.com)

Previously we found that different view-specific information is used to identify a human head from different viewpoints (Nakato and Nagata, 1998 *Perception* **27** Supplement, 131). The aim of the present study was to investigate which spatial frequency (SF) band is most useful for head identification across a viewpoint change. Sixty images of three familiar male professors were used as stimuli. The images were taken from five viewpoints (0°, 45°, 90°, 135° and 180°) and were processed by four band pass filters (8, 16, 32, and 64 cycles per face width). Subjects were asked to identify the professors. The results show that the mean response time significantly decreased as the SF content of the 0°, 45°, 135°, and 180° images increased. For 90° rotation, however, response time was independent of SF. The data suggest that, with the exception of 90°

rotation, the effective SF range in the identification of human heads shifts toward higher peak frequencies as viewpoint changes from the frontal face (0°) to the back of the head (180°). Since the profile was not affected by SF bandwidth, its recognition appears to be unique at least for familiar face processing.

◆ **Finding a face in a crowd: the effect of changes in internal and external facial features**

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Changes in several facial features can make a face conspicuous in a crowd. To investigate which changes are the most effective, observers had to search for a discrepant face amidst distracting faces. Either black-and-white digitised images of real faces or silhouettes and edge representations were used as stimuli. The number of faces in the display was varied and reaction times were measured. Estimates of search efficiency were based on target-trial slopes. The results show that search was very efficient when: (i) the pose change about the vertical or horizontal axis was nearly 90°; (ii) the head was tilted at least 16°. Search was shown to be inefficient when: (i) the pose change was 45° or smaller; (ii) the tilt angle was small (4° or 8°); (iii) the change was based on internal features (eg only the eyes were averted; the eyes were closed, and/or the mouth was open; parts of the target face were hidden in one's hand). Experiments with edge representations and silhouettes suggest that differences in surface properties between a target and a distractor or differences in the shape of facial silhouettes could quite well explain these findings.

◆ **President Lincoln, I presume? How spatial quantisation influences face identification**

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Studies of face recognition with either spatially quantised (block averaged) or low-pass-filtered images reveal a sudden drop in identification rates at resolutions below 16 blocks per face. Performance above this limit is only slightly affected. This seems to indicate a low importance of local (small-scale) features for face identification. To test this hypothesis, I manipulated the position of the quantisation grid. Subjects were tested in a speeded recognition task with coarse quantised versions of 18 male faces. While there was the expected drop of identification performance below about 16 blocks per face, optimising grid position had an unexpectedly strong effect on identification rate. This could be tentatively explained by improvement of the localisation of relatively small features. Identification of pre-experimentally unknown faces may induce a reliance on global features. Therefore, in experiment 2 I used 52 pictures of celebrities which had to be identified at different levels of resolution. Identification performance did not reach an asymptote at 16 blocks per face. Possibly subjects rely on features represented only at finer scales of resolution when recognising familiar faces. Thus, previous experiments on face identification at different spatial resolutions seem to underestimate the influence of local (small-scale) features.

◆ **Categorical perception and semantic information processing of facial expressions**

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According to Etcoff et al (1992 *Cognition* **44** 227–240) and Calder et al (1996 *Visual Cognition* **3** 81–117), facial expressions are perceived categorically. We investigated this issue using three sets of morphed photographic facial images (happiness to anger, surprise, or sadness), generated as in Calder et al's study. Our interest was in whether the experimental data of categorical perception could be explained by continuous dimensions. In experiment 1, subjects discriminated pairs of faces and categorised the emotion shown by each. As in the previous studies, discrimination accuracy was better between categories than within a category. In experiment 2, subjects rated the expressions stimuli using a semantic differential. Factor analysis of the ratings revealed two underlying factors interpretable as 'pleasantness' and 'activity'. We examined the relationship between discrimination accuracy in experiment 1 and semantic distance, defined as the Euclidean distance between pairs of stimuli in the factor space. Discrimination accuracy within a category increased as a function of the semantic distance, whereas between categories remained high, irrespective of the different semantic distances.

◆ **Getting familiar with faces**

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We explored the processing of faces as they became familiar. Twelve subjects were required to learn 30 target faces over 9 sessions, each held on a different day. Targets and distractors were chosen from a set of clean-shaven, young males. On day 1 subjects saw the 30 targets for 5 s each and were then administered a recognition memory test based on the whole face and on internal and external features alone. From day 2 to day 9 the subjects studied the target faces on video sequences, while engaged in activities designed to help them learn the people. Each day they were tested as in day 1 immediately after familiarisation with the entire set of faces. The results showed superior performance for the whole faces over the entire period, and a progressive day-by-day improvement. A comparison of internal-features and external-features conditions showed the former improved more quickly, (both in terms of accuracy and RT) thus indicating a shift in the recognition process due to gained familiarity with the targets. By the end of training, internal features produced better performance than external features, while early on in training performance was generally poorer with internal features.

◆ **Fixation on facial lines plays an important role in judgments of facial expressions**

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We recorded eye movements by the method of corneal reflection while subjects were viewing photographs of morphed faces. Each subject was presented a sequence of 42 different emotional faces (happy, surprised, disgusted, sad, frightened, angry) composed of eyebrows, eyes, nose, and mouth, which were systematically occluded by patches in each session. Subjects were asked to quickly categorise these faces as one of the six expressions of emotion. There were great differences among emotions in the positions and the quantity of fixation points lasting over 70 ms. There were many subjects who concentrated fixation points on the eyes and on the facial lines of unmasked faces. A priority for fixations of outstanding features (eyes, mouth, eyebrows) emerged. Unexpectedly, a considerable amount of fixations on facial lines was found. These results suggest that judgments of facial expressions of emotion can be strongly affected by facial lines (furrows, wrinkles, and subtle creases of the face). Subjects make use of these lines in combination with other outstanding features of the face (ie brows, eyes, mouth).

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◆ **Separation of human faces from background as an adaptive image processing**

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We define the separation of faces from background as a task-dependent process of scene recognition performed at a higher level of the visual system. A computer model for adaptive segmentation of 2-D visual objects (Dudkin et al, 1995 *Human Vision: Visual Processing* **2411** 310–320) has been developed. Preliminary processing, scene description, resulting segmentation are all performed by spatial-frequency filters and feature detectors implemented as multi-parameter self-organised structures which are controlled by processes simulating the 'top–down' (attention) and 'bottom–up' (lateral inhibition) control mechanisms. Initially, the process examines the scene by analysing its spatial brightness distribution. The resulting vector of primary descriptive attributes provides information for several control parameters which are responsible for the creation of primary descriptions: contours and fragments with homogeneous intensity, as well as for the selection of feature-detection operators. These descriptions provide the basis for the scene description and produce a structured environment where the elements are bound together by similar brightness, spatial position, curvature, and texture parameters. The final selection of faces is produced after integrating these elements into scene fragments included in specific hollow facial masks which contain information about eyebrows, eyes, nose, mouth. The measures between these parts of masks provide the topology of facial features.

◆ **A new technique for normalising performance across eccentricities and task complexity**

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Stimulus magnification successfully compensates for extrafoveal inferiority in many simple visual tasks. Despite reports of residual deficits in complex tasks such as face recognition and numeral identification, we have shown previously that treating size and contrast as independent physical characteristics and scaling both separately (ie double-scaling) allows contrast sensitivities for recognition of four faces to be normalised across the visual field. We wished, however, to see how double-scaling requirements changed with increasing task complexity (as defined by the number of faces). We measured r.m.s. contrast sensitivities for detection of one face, discrimination between two faces and recognition from four and eight faces as a function of size at four retinal locations (0–10 deg). In all tasks, foveal maximum sensitivities were higher than peripheral so that simple size-scaling failed. However, all data curves had the same shape, making it possible to equalise performance by double-scaling data for each task separately. Furthermore, owing to the standard shape, every curve could be superimposed onto the foveal detection curve, showing that purely quantitative shifts in size and contrast as a function of eccentricity and task complexity could explain all data variation. The scaling factors required for this superimposition could be fitted with a 3-D scaling-surface equation which explained all performance changes across eccentricity and task complexity.

◆ **Why is face recognition so orientation-sensitive? Psychophysical evidence for an integrative model**

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We investigated the effect of orientation upon the visual processing of faces by selectively altering facial components (experiment 1) or by inducing configural changes (experiment 2). Both experiments revealed a linear increase in RTs of same–different judgments as the second of a pair of sequentially presented faces was rotated away from upright. The analyses of error scores indicated that participants' ability to detect altered components was relatively unaffected by orientation, while orientation had a detrimental effect upon the detection of configural changes. The analysis of transfer effects (experiment 1 followed by experiment 2, and vice versa) revealed that error scores were generally reduced in experiment 2, although such an effect was much less apparent in RTs. These results support the view that (i) mental rotation is needed for the detection of component and configural alterations, and (ii) rotated faces overtax a mental rotation mechanism, thus leading to an impaired activation of holistic representations. Furthermore, these findings have implications concerning an integration of different hypotheses that have been proposed to account for the effects of orientation upon the recognition of faces. An integrative model based on different memory representations, mental rotation, and the dorsal–ventral distinction in visual processing is proposed.

◆ **Seeing a face with an averted gaze reorients one's visual attention**

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Subjects were asked to perform spatially selective manual responses to a reaction signal (an asterisk) presented to the left or right of the attentional focus. The presentation of the reaction signal was preceded by a spatially informative facial cue stimulus. The spatial compatibility between the cue and reaction stimulus was varied: compatible (cued direction and reaction signal on the same side), incompatible (cued direction and reaction signal on the opposite side), and neutral (undirectional cue and reaction signal on the left/right conditions). The results showed that a centrally located front view of a face with its gaze averted 30° to the left/right resulted in facilitated and inhibited reaction times in the compatible and incompatible stimulus conditions, respectively, as compared to reaction times in the neutral stimulus condition (a front-view face looking straight ahead). Instead, a head profile (with a straight gaze) rotated 30° to the left/right did not result in such a response facilitation/inhibition. The reasons for a full-face with an averted gaze but not a head profile eliciting such an attentional re-orientation are discussed.

ILLUSORY CONTOURS, AMODAL COMPLETION, AND OCCLUSION

◆ **Local and global factors in the occlusion phenomena: the effect of context complexity**

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Some two-dimensional line patterns can be seen as figures arranged in depth, so that one partly occludes another. Available data show that there is no single factor that predicts what will be seen behind the occluding figure. Sometimes the local factor prevails: the occluded part will be completed according to the principle of good continuation. Sometimes the global factor prevails: the occluded part will be completed according to the principle of symmetry. The basic idea of this study is that the dominance of local or global factors depends on context complexity. It is hypothesised that complex contexts will result in local solutions, whereas simple contexts will result in global solutions. Line patterns of three complexity conditions were presented: low-complexity conditions included single, open contours; moderate-complexity conditions implied congruity between the occluding and the occluded figure (parallelism, rectangularity); high-complexity conditions included noncongruent occluding/occluded figures. Subjects were asked to draw the contours of the 'occluded' parts in the figures. The results confirmed the initial hypothesis. In the low-complexity condition, symmetry prevailed. In the moderate-complexity condition, completion was ambiguous. Finally, in the high-complexity condition, good continuation dominated.

◆ **Kinetic illusory figures: interaction of information from accretion/deletion of surface texture and surface contours**

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In natural vision, occlusion events usually involve accretion/deletion of both surface texture and surface contours. Both sources of information have been investigated as inducers of illusory contours. However, little is known about their interaction. To study the interaction of texture-related and contour-related information during kinetic occlusions, we explored an illusion of deformation observed when a rigid shape having the same colour as the background is rotated over a set of four solid surfaces (the 'breathing square' illusion). Under these conditions, a strong illusory figure is experienced which appears to pulsate nonrigidly during the rotation. When the same shape is defined by accretion/deletion of texture, the illusion disappears and rigid rotation is perceived. However, if the texture-defined shape is rotated over the four solid surfaces, so that information from both texture and contour occlusions is available, under some conditions the nonrigid pulsation reappears. Thus, the visual system appears partly unable to exploit veridical information from texture occlusions when additional constraints on the formation of a kinetic illusory figure are provided by local contour deformations. We demonstrate the effects of texture density, inducer size, and inducer number on the illusion by means of a number of computer-generated animations. By varying the values of these parameters, other illusions can be perceived with both illusory and texture-defined surfaces, involving weaker losses of rigidity and mislocations of the centre of rotation.

◆ **Illusory figures produced by dot inducers**

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Illusory figures are usually produced by two kinds of inducers: line elements, as in the Ehrenstein pattern, and full-body elements, as in the Kanizsa triangle, either with sharp or diffuse contours. A new kind of inducer is used to produce brightness induction. The basic pattern is made of a matrix of circles, part of which are black and part mid-grey. The 'clouds' of black circles are shaped to form four inducers, as in the classic Kanizsa pattern. The grey circles forming the square matrix enclosed by the 'inducers' seem, in such a condition, brighter than the surrounding grey circles. Such a brightness induction takes place in several variants of the pattern and in the absence of any illusory contour induction. An interesting observation is that, when a single cloud of inducers is isolated, brightness induction does not take place, and the grey circles enclosed in the indentation look darker than other circles of the same luminance. Both effects may be explained in terms of figure–ground segregation.

◆ **Occlusion biases the percept of the geometric effect**

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Ogle's (1938 *Archives of Ophthalmology* **20** 604–623) geometric effect is the percept of a surface slanted about a vertical axis generated by magnifying one eye's image horizontally. We report a situation where the retinal stimulation is identical to the stimulus conditions outlined by Ogle; yet, instead of slant, a depth step is seen. Our stimuli consisted of (i) a vertically oriented white rectangular occluder (11.1 cm × 6.6 cm) in front of two gray rectangles (3.3 cm × 23.3 cm), one with crossed and the other with uncrossed disparity, or (ii) just the unoccluded portions of the gray surfaces. Observers viewed each stimulus once in a stereoscope and reported whether they perceived slant or a depth step. Viewing distance was 65 cm. With the occluder present, the gray rectangle with crossed disparity appeared as slanted 'wings', while the uncrossed rectangle appeared behind the occluder and flat for 7 of 8 observers. When no occluder was present, all observers reported slant according to Ogle's predictions. Our data indicate that occlusion information in the form of monocular zones and T junctions biases the global percept of a stereogram containing ambiguous disparity information.

◆ **Kanizsa's amodal figure made with da Vinci stereopsis**

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We presented stereograms with a monocular stimulus attached to a binocular occluder in each eye so that the shape of the occluded stimulus cannot be judged from the right-eye view or the left-eye view alone. The visual direction of each edge of the occluded stimulus was displaced outward but the shape of the occluded stimulus was judged 'correctly'. Displacements were in the direction opposite to Kanizsa's amodal shrinkage. Results cannot be explained by the idea of Erkelens et al (1996 *Vision Research* **36** 2141–2147) that the cyclopean eye moves to achieve veridical perception for the monocular area. They can be explained, however, by our hypothesis that the visual system displaces a portion of the visual field to fit the two monocular views into a cyclopean one, and that there is an additional shape-perception mechanism that corrects for directional distortions.

◆ **Tunnel effect with moving objects of different lengths**

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The tunnel effect (Burke, 1952 *Quarterly Journal of Experimental Psychology* **4** 121–138) was studied in two experiments. In the first experiment, an object moved at 180 mm s^{-1} and disappeared behind a 20-mm-wide tunnel. Observers adjusted the entry–exit interval until a uniform speed was perceived. Objects of different lengths (bar, square, rectangle) were used. The entry–exit interval for the rectangle was significantly shorter than the one for the bar. The results suggest that the entry–exit interval depends on the interval between the disappearance of the object's tail and reappearance of its head. However, the effect occurs only when the moving object is fixated. In the second experiment, the effect of the object trajectory on the entry–exit interval was studied.

◆ **The transition between a square and an X in Kanizsa's subjective contours**

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In a Kanizsa figure, the shape of the subjective contour changes as the angle of the inducing elements gets more and more acute; a square changes into an X-shape. The threshold angle at which this change occurred was measured in a forced-choice experiment with 15 subjects. The angle of the opened part was varied from 20° to 90° in 10° steps and the radius of the opened part between 11.5% and 26.6% of the subjective-contour length. The shape of the subjective contour changed at an angle of 45° across all radius conditions, but the average threshold angle tended to be smaller with smaller radii. These results suggest that, for large radii, the shape of the subjective contour changes at 45° angles, while distance comes into play for smaller radii.

◆ **Tunnel effect without a tunnel: an overestimation of trajectories**

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A grey disc travels on a white background, at a constant speed (phase A); at a certain point it becomes gradually brighter, until it becomes white (phase B); it remains white for 240 ms (phase C); then it gradually becomes darker until it reaches the brightness of phase A (phase D); at the end it travels with the constant brightness of phase A (phase E). What one sees is a disc that progressively enters a fog bank until its own complete disappearance, and then gradually emerges until its complete visibility. The event exhibits its evident connection with the tunnel effect (Burke, 1952 *Quarterly Journal of Experimental Psychology* **4** 121 – 138), despite the absence of an occluding screen. An experimental problem emerged: the trajectory of 'immersion in the fog' (phase B) seems shorter—both for duration and change in brightness—than the trajectory of 'emersion' (phase D), although the two phases are perfectly symmetric (ratio 1 : 1). The reason of this phenomenal asymmetry was studied by modifying the steepness of the slope of the ascending and descending brightness. The results showed an overevaluation of phase B (immersion): the two phases are judged symmetrical when the ratio is 1 : 2. Increasing the speed of the moving object makes the effect stronger.

◆ **A new interpretation of amodal compression**

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When objects are amodally completed across an occluder, there is a perceived compression in their extent. We investigated why compression occurs, by comparing the spread of attention in amodally completed surfaces across occluders of different extents, using modally completed surfaces as a baseline. A measure of attentional spreading was provided by the extent of Eriksen interference, ie response competition from distractor locations on discrimination responses at target locations. Target and distractor locations were on the same surface, either side of occluders, at a fixed separation. Eriksen interference decreased the larger the area occluded, relative to the modal completion baseline. Prior work has shown that Eriksen interference decreases between separate objects relative to when target and distractor locations are in the same object. We suggest that the visible parts of occluded surfaces may be coded as separate objects, with a probability that increases with occluded area. Then amodal compression becomes an instance of a new illusion (Cooper and Humphreys, submitted *Journal of Experimental Psychology: Human Perception and Performance*) where the perceived distance between two stimuli is smaller when they are parsed as separate objects than as a single object.

◆ **Construals of occlusion in the paintings of René Magritte**

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Perception is not stable. What we see is influenced by cognitive processes such as attention, intention, context, and knowledge. I refer to these changed organisations of the same proximal stimulus as construals: a different perceptual experience of what one is looking at. Ten paintings of the Belgian surrealist, René Magritte, are used to illustrate construals, with a focus on the experience of occlusion. In a three-dimensional world, a requisite feature of our perceptual experience is that of 'behindness' or occlusion. It is here that Magritte is a master at producing the necessary and sufficient conditions to insure construals. He understood the role played by an occluding edge long before the concept existed in the visual sciences. In most of the paintings presented, if one occludes the occluding edge, the result is the elimination of the previously compelling construal. In these images, the forms of occlusion involved are those of figure–ground, transparency, reflection, interposition, complete occlusion, anorthoscopic perception, and amodal completion. A quiz is included.

◆ **Visual completion in 4-month-old infants**

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Four groups of eight infants were each habituated to one of four displays consisting of a grating of either low (0.4 cycle deg^{-1}) or high (1.2 cycles deg^{-1}) spatial frequency, whose central portion was covered up with a horizontal occluder which was either narrow (1.33 deg) or broad (4.17 deg). These displays were called LN (low frequency and narrow occluder), LB (low frequency and broad occluder), HN (high frequency and narrow occluder), and HB (high frequency and broad occluder),

respectively. Posthabituation test displays consisted of a complete grating (CG), along with a separate grating (SG) whose central portion was replaced with a black gap. Infants habituated to the LN, LB, or HN looked significantly longer at the SG than the CG during test trials. Infants habituated to the HB looked at the CG and SG almost equally. These results show that 4-month-old infants can perceive the grating continuation, except in the HB display. In our previous study (Kawabata et al, 1998 *Perception* **27** Supplement, 200), the infants under 1-month-old were able to perceive the grating continuation only in the LN. Thus, our present and previous results indicate that the development of visual completion can be evoked according to the interaction between the grating frequency and the occluder width.

ILLUSIONS

◆ **Perceived patterns of the wagon-wheel effect**

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Perception of the so-called wagon-wheel effect was studied with the use of a rotating disk under stroboscopic light. Four observers were tested. Depending on spoke and strobe frequencies, observers perceive an apparent increase in the number of spokes and a stoppage of the wagon-wheel effect. When the stimulus is presented more than once during the duration of visible persistence, the perceived pattern is a successive additive colour mixture. In achromatic conditions the pattern is affected by luminance contrast between spokes and background; however, the effect occurs also with equiluminous chromatic stimuli. In the wagon-wheel effect, the perceived pattern depends on visible persistence, successive additive colour mixture, luminance contrast, and chromatic contrast.

◆ **Dynamic localisation of equivalent current dipole (ECD) of alpha rhythm during visual**

B042 illusions evoked by flicker with alpha frequency and the scanning hypothesis

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For testing the scanning hypothesis (Pitts and McCulloch, 1947 *Bulletin of Mathematical Biophysics* **9** 57–76) we studied dynamic localisation of equivalent current dipole of alpha rhythm in twelve healthy subjects with 2 ms step using real head model based on magnetic resonance tomography. Subjects were sitting quietly with their eyes closed. The dipole was localised in the occipital cortex and during the development of a single alpha wave it shifted in one or another direction while the dipole moment underwent fan-like rotation mainly in sagittal and horizontal planes. The results obtained indicate changing localisation of the alpha rhythm source along Fissura calcarina (striate cortex). This supports the view that alpha wave reflects the spreading process confirming the scanning hypothesis which is still under discussion.

◆ **A spiral illusion via the Café Wall illusion**

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We have produced a spiral illusion using the Café Wall illusion, in which concentric circles that correspond to 'mortar lines' in the Café Wall figure appear as spirals. This finding suggests the following two observations. One is that spiral illusions are not peculiar to the Fraser illusion. The other is that the Café Wall illusion does not necessarily require linear mortar lines. We have also produced spiral illusions using several illusions resembling the Café Wall illusion as well as the Zöllner illusion. We demonstrate these illusions and discuss them in terms of analysis and integration of local features.

◆ **Composition of two illusory figures**

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Measurements of illusions have been performed on two superposed Müller-Lyer figures combined into one stimulus. In computer presentations, the two figures had the same structure, size, and horizontal orientation, but differed in the tilt angles α_1, α_2, and wing lengths w_1, w_2. The illusion: (i) exceeded its maximum value (Bulatov et al, 1997 *Biological Cybernetics* **77** 395–406) when $\alpha_2 < \alpha_1$, (ii) was less than it when $\alpha_2 < \alpha_1 < 90°$, (iii) decreased gradually with increase of α_2 from α_1 to 90° approaching zero in the region of 90°; (iv) attained negative values when $\alpha_2 > 90°$; (v) was less than 10% within the range 90° to 135°; (vi) vanished in the region of 135°; (vii) grew again with further increase of α_2; (viii) was absent when $w_1 = w_2$, $\alpha_1 = 45°$, and $\alpha_2 = 135°$; (ix) appeared and increased gradually with difference between w_1 and w_2, attaining positive values when $w_1 < w_2$, but negative ones when $w_1 > w_2$. These data are interpreted in terms of two-dimensional spatial filtering in the retinocortical pathways and have been reproduced quantitatively by modelling.

◆ **Contrast effect on illusion summation**

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Paired Müller-Lyer figures have been used to measure distortions of perceived length as a function of the contrast of the stimuli. On the monitor, paired figures differed in contrast and orientation (by 180°) but had equal size and shape and overlapped precisely, matching arrow tips. The shaft line was absent. The data show that illusion strength increased gradually with increases in the contrast difference from 0% to 50% but decreased with further increase of the difference from 50% to 100%; the two slopes of the function had quite similar profiles, and the experimental curve was practically symmetric. The same results have been obtained with two overlapping Oppel–Kundt figures with the same spatial structure and size but different contrast and orientation (180°). It could be supposed that geometrical illusions evoked by white and black stimuli superpose in the same way as those evoked by two white or two black stimuli. The data have been reinterpreted in terms of two-dimensional spatial filtering in the neural retinocortical pathways and fit well with the predictions of a neurophysiological filtering model (Bulatov et al, 1997 *Biological Cybernetics* **77** 395–406).

◆ **Temporal properties of depth filling-in**

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The depth of an untextured horizontal line is ambiguous because there is an infinite number of possible correspondences between left and right images. However, it is known that the percept for such a visual pattern is a flat line at the depth of its endpoints, at which the correspondences are unique (Nakayama and Shimojo, 1992 *Science* **257** 1357–1363). This suggests that the depth of the central part of a horizontal line is completed with that of its endpoints. To investigate the dynamical process of this completion, we measured the perceptual depth change at the centre of a horizontal line when the depth of its endpoints oscillated sinusoidally. A short vertical line was shown at the centre of the horizontal line as a depth probe. The phase difference between the endpoints and the centre was measured by subject's adjustment of the phase of the probe so that it seemed to oscillate together with the horizontal line. The length and the vertical position of the horizontal line were varied. For the longer lines, subjects perceived a larger phase delay. For large eccentricity, they perceived smaller delay. These results indicate that the depth filling-in is carried out by a neural mechanism which necessitates propagation time increasing monotonically according to the length to be completed.

◆ **Dynamic structural shape change in pantomime effect with binocular viewing**

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A transparent volumetric illusory object filled with a transparent medium is perceived when inducing objects are arranged in suitable relations and displayed stereoscopically. We named this phenomenon the pantomime effect. The pantomime effect is induced by sustaining cues (Zhang and Idesawa, 1998 *Japanese Journal of Applied Physics* **37–38** L329–L332), whereas opaque illusory objects are induced by occlusion cues (Idesawa and Zhang, 1997 *Proceedings of the SPIE* **3077** 770–781). When sustaining cues change continuously in position and orientation between two different conditions, dynamic structural shape changes (fusion and separation) can be perceived. In addition, hysteresis in the transition between separation and fusion of illusory objects is observed. The human visual system probably tends to retain the previously perceived structure, so that the structural transition is delayed until the geometric conditions reach a threshold value. A similar effect is observed in the case of opaque illusory objects. Hysteresis is stronger for horizontal than for vertical transitions. In addition, transparent illusory objects are difficult to separate but easy to fuse in comparison with opaque illusory objects.

◆ **The Pulfrich effect in directionally ambiguous motion**

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Owing to the asymmetry between horizontal and vertical disparity, the Pulfrich effect yields perceived depth for horizontally moving objects but not for vertically moving ones. The Pulfrich effect was measured by translating oblique lines seen through a circular window, which made line direction ambiguous. Overlaying random dots that moved horizontally, vertically, or diagonally

controlled the perceptual motion direction of the lines. When the lines were seen to move horizontally, the effect was strongest in spite of the same physical motion of the lines. Another experiment was performed to test whether the pseudo-disparity direction of the dots captured the ambiguous pseudo-disparity direction of the lines. The overlaid dots were displayed for one eye only. The result was that the Pulfrich effect was always strong in spite of perceptual changes in motion direction. The Pulfrich effect was determined by the horizontal disparity component independently of perceived motion direction. These results demonstrate that the aperture problems in motion and stereopsis for oblique lines are solved independently.

◆ **Influence of 2-D image properties on the error distribution of dot localisation in affine**
B049 reference frames

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Subjects were shown two four-dot patterns: a model pattern in which each of the dots was fixed, and a test pattern in which one of the four dots could be positioned with the computer mouse. Subjects were asked to reproduce the model pattern by moving the fourth dot. In some conditions, model and test patterns differed from each other only by a translation in the plane (the control condition), while in other conditions they differed from each other in slant. The two-dimensional median of the estimations was calculated. Deviations of this measure from the veridical position of the fourth dot were small on average. However, the sizes of the covariance ellipses that were fitted to the estimations depended heavily on the difference in slant between model and test pattern and on the position of the fourth dot relative to the fixed reference points, indicating differences in uncertainty between conditions about the position to be estimated. Finally, the covariance ellipses were elongated in some of the nonzero slant conditions, indicating that subjects probably used 'qualitative' reference axes, which they did not need in the control conditions.

◆ **The scintillating grid illusion as a function of retinal eccentricity**
B050

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The scintillating grid illusion results when small bright discs are superimposed upon the intersections of a Hermann grid (Schrauf et al, 1997 *Vision Research* **37** 1033–1038). Illusory dark spots are perceived at the bar intersections with each flick of the eye. In the present study, the retinal eccentricity at which the illusion disappeared for grids varying in size was measured. Results show that, with increasing retinal eccentricity, the pattern size necessary to produce the illusion increases. The slope of the function relating the two variables is greater than that found for perceptive fields measured with the Hermann grid illusion (Spillmann, 1994 *Perception* **23** 691–708). While the M-factor measured with the Hermann grid corresponds well with that of neurons in V1 (Tootell et al, 1988 *Journal of Neuroscience* **8** 1531–1568), for the scintillating grid the correspondence is best with that obtained for neurons in the dorsomedial and dorsointermediate cortex of the Marmoset monkey (Rosa and Schmid, 1995 *Journal of Comparative Neurology* **359** 272–299) which have larger receptive fields and integrate over a larger retinal area. This suggests that the perceptual fields for scintillating grids involve the integrated activity of large, overlapping receptive fields at higher levels.

◆ **Transient and sustained components of orientation illusions**
B051

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Orientation illusions which occur whenever a vertical (or horizontal) 1-D test grating is surrounded by another 1-D inducing grating can be shown to have opposing effects contingent on a number of stimulus parameters. These opposing effects have been claimed to result from different orientation-processing mechanisms. In particular, orientation-repulsion effects are thought to arise in V1 and are sensitive to spatial and temporal parameters, whereas orientation-attraction effects are held to arise in extrastriate cortex and are generally insensitive to such manipulations. When it was reported (Wolfe, 1984 *Vision Research* **24** 1959–1964) that orientation-repulsion aftereffects occurred with short test flashes, Wolfe postulated that either there are distinct mechanisms which process brief and longer-duration stimuli; or that there are distinct mechanisms which do not primarily process duration but are differentially responsive to temporal parameters, amongst several others. We present data to suggest that large orientation-repulsion effects can be induced with stimulus parameters other than duration, including contrast and spatial frequency. The effect of these stimulus manipulations, however, are attenuated if the transient components of stimulus presentation are removed by means of a ramped increase in luminance contrast.

◆ **Stereo from Café Wall distortion**

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The Café Wall is a chess board with alternate rows displaced by half a square, with narrow 'mortar' lines of intermediate luminance between the rows. The rows of 'tiles' appear as long wedges. Gregory and Heard (1979 *Perception* **8** 365–380) found that the illusion depends critically on the luminance and width of its mortar lines, and the contrast of the alternate light and dark tiles. It is supposed that small-scale tilts are produced by the local asymmetries of pairs of tiles—which are integrated by a second process into the long wedges. Morgan and Moulden (1986 *Vision Research* **26** 1793–1800) suggested that the local tilts are due to Laplacian filtering. We have produced new versions of the Café Wall which give both horizontal and vertical tilt distortions. We have presented opposite illusory vertical tilts to each eye, and find that these give a stereoscopic tilt in depth, though with some rivalry, as these patterns necessarily produce opposite contrast tiles for fusion. To reduce rivalry, we have presented a vertical tilt illusion to one eye and a similar but non-illusory figure to the other. Analysing various stereo stimuli indicates, however, no significant propagation of illusory tilt into stereo depth.

◆ **A basic element to explain illusory geometrical distortion**

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In 1908 James Fraser suggested that the essential element of the Münsterberg, or Café Wall, illusion, was a pair of bricks of the same colour (eg black) joined at their opposite corners by a mortar line. Today this explanation has been extended to encompass computational models of early visual processing (eg Laplacian spatial filtering) which generate, as a side-effect, a small tilt cue centred on each 'essential' element. However, we contend that this is an incomplete explanation (a) because it is possible to reduce Fraser's two-brick element into two (antisymmetric) single-brick units (each retaining its own short bar of the mortar) whilst preserving their power to tilt parallel lines, and (b) because filtering these units produces little or no tilt bias. Converting to this new single-brick limiting case it is possible (i) to explain the Café Wall illusion, (ii) introduce a series of new illusions constructed from this element, and (iii) propose a theory to explain all these cases. This theory comprises a local tilt distortion occurring at each single-brick element and an interaction of global grouping processes acting on multiple elements. It derives from work on the illusion of angularity (Pinna, 1991 *Perception* **20** 207–218).

◆ **Dynamic length changes of a rotating arc—evidence for interocular transfer**

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The length of a white rotating arc on a black disk is almost never seen veridically. After initial exposure, it first appears to contract, then expand, and to reach an asymptote after 10–15 s. For arc lengths between 36 and 72 deg, the apparent shrinkage is 18% while the elongation is 240%. For shorter arcs of 9 and 18 deg, there is no shrinkage, just expansion to approximately 500%. Observation with two-coloured arcs shows that the lengthening derives predominantly from the trailing end of the stimulus. We examined the time-course of decay of apparent elongation from its asymptotic value. It decays to physical stimulus length within a period 7 s; however, upon re-exposure the arc requires only half the original time to reach the asymptote ('priming'). Curiously, after adapting to the stimulus with one eye and then viewing it with the other, the exaggerated length is largely maintained. Likewise, after adapting to the arc in one direction (clockwise) and thereafter viewing it in the opposite direction (counterclockwise), the arc appears to expand more rapidly. These findings invite an explanation in terms of cortical neurons with binocular input, but without directional specificity.

◆ **On the Benussi effect in a kinetic field**

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A study is reported of observers' perception of displays in which a black square (side 57 min of arc) is transformed into a rectangle (side 6.6 deg) by the outward motion of the right vertical edge. This display is seen as a rectangle that lengthens horizontally to the right. If a vertical bar is superimposed on the path of the rectangle, it is seen as two separate shapes on either side of

the bar, one motionless and the other expanding in horizontal direction. This is an example of the Benussi effect in a kinetic field [Vicario, 1997, in *La Percezione degli Eventi* Eds G B Vicario, E Zambianchi (Milan: Guerini) pp 266–274]. We tested the conditions in which 12 observers (80 trials each) perceived a stationary shape on the left side of the vertical bar, varying the position of the bar (across 5 values) and the velocity of expansion of the rectangle (across 4 values). The results indicate that a stationary shape is perceived on the left side of the bar only when the expanding process on the right of the bar lasts more than 380 ms, regardless of the position of the bar or the velocity of expansion.

NATURAL SCENES AND OBJECTS

◆ Information or representation? A case study in 3-D symmetry discrimination

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The purpose of our study was to dissociate stimulus information from internal object representation in a symmetry discrimination task, in order to correctly infer the nature of internal representations. A prototype object was created by linking four cylinders into a chain that was mirror symmetric in 3-D. Two stimulus objects were then generated by adding 3-D Gaussian perturbations to the vertices of the prototype. Subjects decided which of the two was more similar to the prototype. The Gaussians were either independent from vertex to vertex, so that the resultant objects were asymmetric. Or they were symmetric, and so were the resultant objects—of which half the stimulus information was redundant. The ideal observer was also derived for the task. We found subjects' threshold greater for symmetric than for asymmetric objects ($F_{1,11} = 4.72$, $p < 0.05$). However, this inequality is reversed when statistical efficiency, which takes into account stimulus information, is plotted instead. It is more efficient to discriminate symmetric objects: 22.48% versus 16.67% ($F_{1,11} = 12.42$, $p < 0.005$). We conclude that symmetric objects are more precisely represented. Without the ideal-observer analysis, a wrong conclusion would have been drawn.

◆ Matched filtering of chromatic images by the human visual system

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Our aim was experimental verification of the applicability of ideal observer theory (matched filtering) to the case of chromatic images observed under threshold conditions. We measured and compared correct-identification probabilities of the exactly known test objects in noisy chromatic images by a human observer and a computer model of an ideal observer. Measurements were performed both for pure chromatic (isoluminant) images and for images made up of pixels with different luminance and colour. The results of measurements allowed us to formulate the following conclusions. Addition of pure chromatic noise to achromatic images of the test object (or vice versa) does not reduce correct-identification probability. When test objects are identified in noisy pure chromatic images (R–G or B–Y), the human visual system and the ideal observer model give approximately the same results. If images of the test objects with added noise have achromatic and chromatic contrasts, the matched filtering also takes place. The resulting signal-to-noise ratio N defining the correct-identification probability by a human observer is: $N = [(N_L)^2 + (N_{R-G})^2 + (N_{B-Y})^2]^{1/2}$, where N_L, N_{R-G}, N_{B-Y} are values of signal-to-noise ratio for achromatic and chromatic (R–G and B–Y) signal components. The general implications of this model are discussed.

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◆ Recognition in early visual attention

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Mannan et al (1995 *Spatial Vision* **9** 363–386) and Kohler et al [1995 *Journal of Physiology (London)* **485** 25–26] have shown that, when viewing scenes that are difficult to recognise, the fixations involved in the first 1.5 s are largely determined by 2-D geometrical or spatial features of the image and are not influenced by recognition or other observer-specific mechanisms. To study the role that these 2-D geometrical features might play in an early stage of recognition we made three computer simulations. Each of them attends to: (a) random, (b) non-2-D geometrical, and (c) 2-D geometrical points of the image. The recognition stage is common for the three simulations. All three algorithms were tested in two different applications: room recognition (20 rooms) and face recognition (100 people). In general, while simulation (c) needed only to

attend to a small number of points of the image (10 to 15) to achieve identification, simulations (a) and (b) either were much slower (25 to 30 points required) or resulted in identification failures. We conclude that human attention mechanisms might be directed to 2-D geometrical features of the scene because these areas usually contain good information for describing and discriminating between objects.

◆ **Foveal versus peripheral information processing during scene perception**

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Foveal and peripheral information processing during free scene exploration was studied by eye-contingent display-change techniques. Participants explored line drawings of real-world situations, in the context of an object-decision task. Eye movements were recorded, and used on-line to align a moving window with the fixation position. In four experiments, information inside or outside the foveal window was masked, while the remaining part of the scene remained visible. Masking occurred during a preset interval at the beginning, or after a preset delay following the onset of each fixation. During the remaining period, the mask was removed, and the undegraded scene was completely visible. Participants self-terminated the scene presentations, and therefore the scene inspection time was considered a measure of overall task difficulty. Additionally, for each trial the mean fixation duration and saccadic amplitude were calculated. It was shown that foveal information is mainly required during the early part of fixations. When foveal encoding is hampered during this period, fixations are sustained. Conversely, peripheral processing is less bound to a clearly defined interval. Furthermore, degradation of the peripheral image is mainly reflected by saccadic amplitudes, rather than fixation durations. These findings are discussed in the context of models of eye-movement control.

◆ **Cardboard cut-out phenomenon in virtual-reality environment**

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In stereo pictures, objects such as human bodies themselves often appear flat, although depth between the objects is visible. Very short distances typically used for viewing stereo pictures might account for this phenomenon, since relative depth from binocular disparity is scaled by the square of the distance. This scaling hypothesis was examined here by analysing the phenomenon with stereo pictures, including real-sized ones, viewed in a virtual reality (VR) environment. Stereo pictures of a human model were taken at 0.62, 1.25, 2.5, 5, and 10 m. These pictures were presented in a large-scale, back-projection VR environment, and viewed from 0.62, 1.25, or 2.5 m with LC shutters. The image sizes were kept constant in visual angle.

In most conditions, subjects did not experience flat appearance. Relatively flat ratings were obtained for the shortest viewing distance with a long shooting distance, but this was not comprehensive. These results indicate that the scaling hypothesis only partially accounts for the phenomenon. Contributions from figural cues seem important, since monocular viewing produced similar results in some conditions. Additional factors, such as background types, background focusing, or convergence did not affect the results significantly.

◆ **The orthogonality assumption in comparing simple 3-D objects from different viewpoints**

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Willems and Wagemans (1999, submitted) found that the detection of orthogonal angles from a projected image of these angles depended on the variability of the projected orthogonal angle with variable positions in space. We investigated whether this result could be extended to the task of discriminating between orthogonal and oblique angles with different levels of obliqueness. Subjects were presented with two pictures of simple 3-D objects (cross-like figures), side-by-side on the screen, one of which (the 'reference object') was viewed head-on (ie positioned in the frontoparallel plane) while the other (the 'test object') was viewed from aside (ie positioned in depth). Subjects had to indicate whether the two pictures could be depicting the same 3-D object. When discriminating between an orthogonal reference cross and an oblique test cross, a large number of false alarms were made when the oblique cross could still be interpreted as an orthogonal cross from a very oblique position. Even when discriminating between two oblique crosses, performance depended heavily on this orthogonality bias and its relation with image variability. The results are discussed in the light of the role of the orthogonality assumption and different normalisation approaches used by the human visual system.

◆ **The interaction of size and level of categorisation**

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Recent work (Archambault et al, 1999 *Psychological Science* in press) has shown that the nature of the categorisations (general or specific) can influence the perceived properties of an identical distal object. Here, we examined further the nature of object information that is available for general and specific categorisations. Human observers can recognise objects at different scales. We examined how changing scale information changed categorisation performance at the general (categorise an animal as a dog) and specific (categorise an animal as a Labrador) levels. Stimuli were 3-D, computer-synthesised animals. The task was to decide whether two sequentially presented animals were the same, at a general or a specific level. Stimuli were presented at a large, or a small scale. We hypothesised that critical information for specific categorisations would be removed from small-scale objects. Results indicate that similarity judgments were less accurate when the two animals were presented at a small scale for specific judgments. This difference, however, was not observed for judgments at a more general level of categorisation. The results therefore suggest that scale-specific information taps differently into general and specific-level categorisations.

◆ **Judgments of structure in depth in cue-poor regions rely on independent heuristics,**

B063 **not logical propagation**

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Visual scenes often contain regions with few obvious depth cues. Three-dimensional structure there might be gauged either by logical propagation (ie reasoning from cue-rich regions elsewhere) or heuristically (ie deriving information from local relationships other than standard cues). To test these alternatives, pictures of cue-poor structures, triangles slanted in depth, were presented alone or in context of a cue-rich cube, with its base in the same plane as the triangle; and/or a cue-poor support surface, with the triangle at one end and the cube (if one was present) at the other. Ten subjects reported the perceived structure of the triangles, using probes to indicate perceived slant and tilt, and judging the relative lengths of the sides. Including cubes increased confidence ($F_{1,9} = 5.2$, $p = 0.048$) and improved judgments of tilt ($F_{1,9} = 9.6$, $p = 0.013$) and slant ($F_{1,9} = 6.8$, $p = 0.028$). However, including supports improved slant estimates more ($F_{1,9} = 111.4$, $p < 0.001$), and did not interact with cube presence—both contrary to logical propagation models. Also length judgments, though geometrically coupled to slant, depended mainly on a different factor (triangle shape). These findings suggest multiple, weakly coupled heuristics rather than logical propagation.

◆ **How children drive and map in a simulated environment**

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An observer needs to drive safely in a cluttered environment. How far are children able to drive in a simulated environment and to map landmarks? We simulated the observer's displacement towards a group of trees which are unreachable. The virtual camera focuses on a specific tree (FT) during all the displacement wherever the observer is driving. Performances of children aged 8 and 10 years were compared in three successive tasks. First, observers were asked to drive towards FT (single driving task). Second, they had to replace some missing trees on a map after each driving trial (double task, DT). Finally, we reran recorded DT trajectories and observers were only asked to map (single mapping task, SMT). For each trial, we recorded the angle error between the displacement and gaze directions. Results show that DT impairs performances in both driving and mapping. Whereas the 10-year-old children perform significantly better in mapping, the two groups do not differ as far as driving is concerned. Similarly to what we observed with adult groups in other experiments, DT impairs children's performances. Although visual stimulation is exactly the same for DT and SMT, the action of driving seems to disturb mapping.

◆ **A computational model predicts discrimination thresholds for morphed objects in natural scenes**

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We have previously shown that the human visual system is optimised to encode the information in the natural visual environment. This has been demonstrated psychophysically by comparing people's discrimination thresholds for small spatial changes (produced by 'morphing') in natural and unnatural (spectral slope modified) visual stimuli. We have now developed a relatively simple computational model of the low-level discrimination process to explain these results. We calculate differences in contrast between two images (reference and test) within a number of spatial-frequency channels designed to have the spatial-frequency bandwidth of simple cells in the visual cortex (about 1 – 1.5 octaves). Our model presumes that simple cells in several independent spatial-frequency bands sample the reference and test stimuli point-by-point, and that each cell then signals any local differences in the spatial structure of the two stimuli. By 'customising' the model to include each observer's contrast sensitivity to sinusoidal gratings, we are able to replicate the forms of the relationships between discrimination threshold and spectral slope, and the ways that these differ between picture sets and observers. Our results support the view that many of the properties of the human visual system (bandwidths of neural filters, shape of the contrast sensitivity function, etc) are tuned for optimal performance for discrimination tasks in a natural environment.

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◆ **Nonuniform phase perturbations in natural images**

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Several researchers have investigated the effects on visual perception of perturbing the global Fourier phase spectra of images; perturbations studied include randomisation, quantisation, and hybridisation. Since the results of these studies, in which perturbations were applied uniformly over the 2-D Fourier domain, illustrate that Fourier-phase information is critical to the scene perception, we decided to modify the techniques so as to perturb the phase spectra of images in a manner which depended on spatial frequency and/or orientation. These nonuniform phase perturbations were applied to both a library of calibrated natural scenes and a library of random textures. The results, illustrated by way of a number of suprathreshold demonstrations, indicate that, for natural images, the salience of these nonuniform phase perturbations depends (i) on which areas of the 2-D polar Fourier domain are perturbed, and (ii) the range (over spatial frequency or orientation) of components which are perturbed. These dependences are not present in the case of the random textures; thus, an explanation of the visual effects must take account of the higher-order structure of natural scenes. A simplified model of fourth-order scene structure (Thomson, 1999 *Journal of the Optical Society of America A* **16** 1549 – 1553) can account for the results.

◆ **Measurements of the human visual system efficiency under threshold conditions**

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The efficiency of the human visual system under threshold conditions is usually expressed as $k = E_i/E_h$, where E_i and E_h are contrast energies for an ideal observer and human observer, respectively, for detection (or identification) of test objects with probability p. We assumed that observers had full knowledge of the characteristics of the test objects. The purpose of the work was to investigate the dependence of efficiency on the intensity of external noise added to the image of the test objects with and without a priori information about the coordinates and sizes of the objects. We measured and compared correct-identification probabilities of test objects in noisy images by human observers and by a computer model of an ideal observer. We found that if observers have a priori information about all parameters of the test objects, the efficiency is $\sim$1 over a wide range of noise intensities. If observers have no a priori information about the sizes of the test objects, the efficiency is still close to 1 over a wide range of noise intensities, but decreases at very high noise intensities. Without a priori knowledge of the test object coordinates, a strong drop in efficiency takes place as the noise increases.

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◆ **The effectiveness of different segregation cues in an object-detection task**

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We investigated the effectiveness of colour, luminance, orientation, density, and motion segregation cues in psychophysical tasks of object detection. In a 2AFC object-detection task we established a level of subjective equality between the different segregation cues by varying cue intensity and measuring subject accuracy. To investigate the relative effectiveness of the different cues, objects were defined at the levels of subjective equality but the stimulus duration was varied according to subject performance in a 3AFC staircase paradigm. The combinatorial effects of the segregation cues were explored by allocating two segregation cues to define an object and comparing subject performance in a 2AFC object-detection task to that obtained when only one of the cues was available. Results suggested that colour, luminance and orientation segregation cues were equally effective, whereas density and motion cues were less effective in enabling the segregation of objects from their background. Motion and luminance cues appeared most effective when combined, but cue combinations were more effective in precipitating segregation than the presentation of any cue alone. The implications and possible physiological basis of these results to our understanding of image decomposition in the human visual system are discussed.

◆ **Sparse cortical coding and object recognition**

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Cells in the primate visual cortex are selectively sensitive to different orientations and spatial frequencies. According to current theories, these form a sparse, distributed representation of natural scenes (Bell and Sejnowski, 1997 *Vision Research* **37** 3327–3338). The reason offered for the development of sparse representations is typically 'redundancy reduction'. Most work has concentrated on how to evolve the sparse descriptions. We propose that a more meaningful metric is one which relates to the tasks an animal performs, eg object recognition. We are developing a model of retino-cortical processing for automatic recognition. It incorporates retinal gain control, multiscale band-pass filters with a fovea, and a sparse multiscale 'cortex' of frequency-selective and orientation-selective processes. We have employed associative techniques for assessing how well the sparse representation captures the information in an image, and have concluded that this approach does not provide a good criterion for assessing the benefits of different representations. We are now incorporating a simple object-recognition stage into the model. In this paper we describe the model and the metrics applied to the sparse representations, and demonstrate the effects of different representations on recognition performance.

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◆ **Determinants of shape perception and object recognition**

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We demonstrate that performance on an object-recognition task can be explained in terms of observer-specific psychometric profiles. These profiles were derived from a battery of tests, including the effect of stereo, texture, outline (occluding contour), and motion cues on judgments of 3-D surface curvature. Our findings are twofold. First, when estimating surface shape, observer dependence on stereo cues is negatively correlated with dependence on motion and occluding-contour cues. Second, in a separate task in which observers learned to recognise novel objects, a regression analysis revealed that three psychometric variables accounted for 75% of the variance in learning rate. These variables are simple reaction time, and the extent to which an observer's shape judgements depend on motion and outline cues. The implications of these findings for the existence of observer-specific 'perceptual styles', and their relation to the fundamental psychophysical competences associated with object recognition are discussed.

◆ **Rapid object recognition based on asynchronous feed-forward processing**

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In humans, 150 ms of processing is sufficient to detect the presence of a target in briefly flashed photographs of natural scenes [Thorpe et al, 1996 *Nature (London)* **381** 520], and in monkeys, processing time is probably even shorter (Fabre-Thorpe et al, 1998 *Neuroreport* **9** 303). We propose a biologically plausible model for object recognition consistent with this sort of rapid processing that involves a hierarchically organised system of asynchronously discharging integrate-and-fire

neurons. Starting with the retina, the earliest firing cells are those with the strongest inputs. At subsequent stages, more complex receptive field properties result from a desensitisation mechanism which makes neurons sensitive to the order in which their inputs fire. The final processing layers contain very large numbers of neurons trained to particular views of the various targets. Competitive inhibitory mechanisms mean that, once one unit has fired, activation of other units with receptive fields in the same part of visual space becomes increasingly difficult. Simulations using SpikeNET, a software system designed for modelling networks with millions of integrate-and-fire neurons and billions of synapses, demonstrate that architectures based on these principles can indeed be used to perform sophisticated object recognition with natural scenes.

◆ **Visual segmentation of 88 outlines of everyday objects: bottom–up versus top–down**
B072 and contours versus shapes

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Most experiments on visual shape segmentation have been conducted with abstract, meaningless stimuli. The goal of this study was to investigate how humans segment outline drawings of everyday objects instead of meaningless shapes. In a large-scale paper-and-pencil experiment, participants ($N = 400$) were asked to segment outline versions derived from a standard set of line drawings of 260 everyday objects (Snodgrass and Vanderwart, 1980 *Journal of Experimental Psychology: Human Learning and Memory* **6** 174–215). On the basis of results from a previous study (Ploeger et al, 1998 *Perception* **27** Supplement, 123), 88 outlines were selected that were either easy or difficult to identify (44 in each condition). Half of the participants were asked to segment the contours, while the others were asked to segment the shapes as such. Each subject received only 22 outlines (11 'easy', 11 'difficult'). All segmentations were entered in files with the x, y coordinates of the outlines to enable automatic analysis of the results, including how well the segmentations approached the singularities of curvature (negative minima, positive maxima, and inflections). The results are discussed in relation to theories of object segmentation (eg Hoffman and Richards, 1984 *Cognition* **18** 65–96; Siddiqi et al, 1996 *Perception* **25** 399–424).

◆ **Factors in visual object recognition**
B073

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Recognition of visual objects is affected by different factors, such as orientation, degradation of physical information, and category. The interaction of these factors was investigated by presenting pictures belonging to different categories (animals, vegetables, objects) at several degrees of fragmentation, in ascending way (Viggiano and Kutas, 1998 *Electroencephalography and Clinical Neurophysiology* **108** 435–439), and different orientations (0°, 60°, 120°). Subjects ($N = 16$) were requested to identify the stimulus. The amount of information necessary to identify the pictures depended on both orientation and category. In particular, the identification of animals was strictly related to orientation; vegetables were not affected by orientation at all; for objects, more amount of information was necessary when the orientation was different from 0°. Reaction times were affected by stimulus orientation, independently of category.

◆ **Using chimerae to probe part–whole relationships in the recognition of impoverished**
B074 and detailed pictures

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The part–whole debate is central to understanding object recognition in general. However, very little work addresses the issue. Furthermore, where the issue has been raised, work concentrates upon perceptually represented parts. How conceptually represented parts are recognised has received sparse attention. Here, four experiments address conceptual part recognition. A technique commonly used in face and word recognition—embedding parts within coherent and incoherent wholes—is employed. Incoherent wholes were formed by combining halves from two different objects. These objects are called chimerae. The first experiment, in which silhouette objects were used, showed that conceptual level recognition of parts involves complex part–whole interactions and that processing is object-dependent. The second experiment showed that these effects persist when local information is available. Experiment three demonstrated that early holistic processing occurs and that this is not object-dependent. Experiment four showed that this holistic processing is concerned with object shape. These results, combined with contemporary theory, allowed us to develop a general model of object recognition. The model suggests that there may be three mechanisms involved in object recognition. The first processes perceptually represented parts, the second processes object shape, and the third processes conceptually represented parts.

NEURAL NETWORKS

◆ **Emergence of complex cell properties in a neural network that maximises the sparseness**
B075 of local energies

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A useful approach to modelling the properties of visual neurons is based on statistical generative models of natural images. Olshausen and Field [1996 *Nature (London)* **381** 607–609)] showed that the estimation of a simple linear generative model can be performed by maximising the sparseness of the underlying image components. Sparseness is a statistical property that expresses the 'spiky' non-Gaussian shape of the probability density function of the component. Olshausen and Field used natural image patches as training data (input) to a neural network that learned according to this estimation principle, and observed emergence of linear features that closely resemble simple-cell receptive fields. We show here that this same principle can explain the emergence of the principal properties of complex cells as well. We modelled complex-cell responses using classical (local) energy models, and derived a learning rule for a neural network to maximise the sparseness of the responses. We trained the neural network using 16×16 pixel monochrome image patches from natural scenes as the input data. Thus we obtained features that had the principal properties of complex cells: phase and (limited) shift invariance, in addition to orientation and frequency selectivity.

◆ **Neural network for perceptual grouping and lightness perception**
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The Munker–White illusion, Benary's cross, checkerboard contrast, and second-order simultaneous contrast are examples of perceptual phenomena that could not be explained by classical concepts such as Wallach's ratio rule and centre–surround antagonism. Since such illusions involve two or more aligned borders with different magnitudes of contrast, it is proposed that a low-contrast contour receives stronger support if it is aligned with a high-contrast contour and therefore performs contrast negation in a filling-in layer. To implement this hypothesis the bipole cell model of perceptual grouping has been revised. The new model exhibits analog sensitivity and operates as a statistical MAX gate rather than an AND gate. Both features are consequences of presynaptic inhibition embedded in cooperative interactions. A MAX gate means that the bipole cell inherits activity level from the lobe that samples stronger contrast. Computer simulations have been performed with a neural network for lightness perception formulated in the tradition of filling-in theories. The network has four stages: (1) cells with centre–surround receptive fields; (2) simple and complex cells; (3) bipole cells; (4) filling-in, which combines signals from stages 1 and 3. Activity distributions in the filling-in layer show that the model correctly predicts appearance of grey patches in all illusions mentioned here.

◆ **Neural network for colour constancy**
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Colour constancy is the perceived stability of the colour of objects under different illuminants. We need to see at least two coloured objects in the vision field in order to achieve colour constancy. We created a four-layer neural network. Its inputs were two sets of RGB receptors, one set for the test chip and another for the background. The second layer consisted of two sets of colour-opponent cells (for the test chip and the background). The third layer formed the layer of hidden cells of the back-propagation network. The fourth layer consisted of three output neurons signalling x, y, Y coordinates (1976 CIE). For training, we used five illuminants: a (near A: $x/y = 0.448/0.408$), bluish ($x/y = 0.232/0.232$), C′ ($x/y = 0.31/0.316$), greenish ($x/y = 0.285/0.399$), and purple ($x/y = 0.326/0.263$). For testing we included four more illuminants: yellow ($x/y = 0.367/0.446$), violet ($x/y = 0.273/0.232$), red ($x/y = 0.367/0.29$), and blue-green ($x/y = 0.251/0.343$). The best learning results were achieved when learning was simultaneously performed with all five illuminants. In this case, tests for all nine illuminants gave good results. When the background was switched off (black), the neural network was unable to perform the task.

◆ **On a feedforward network model developing orientation selectivities in V1 cells**

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We analysed mathematically Linsker's network concerning the development of orientation selectivity in V1 cells using numerical experiments. Since we were mainly interested in the development of orientation-selective cells, we did not take the horizontal connections among V1 cells into account. We made the following assumptions: (i) synaptic connections between V1 and LGN cells would be modified by a linear Hebbian rule; (ii) correlation of activities of LGN cells is described as a DOG function. The development of orientation selectivity is determined by two parameters of learning equations: the distribution of initial weights and a correlation function. We explained the mathematical meaning of these two parameters concerning development of orientation-selective cells by using the Fourier transforms of those parameters. We also pointed out the meaning of Linsker's parameters k_1, k_2. The prominent phase and orientation in a V1 cell should be computed as soon as initial synaptic weights are assigned. On the other hand, correlation functions determined the spatial frequency in the cell. Our results indicate that the development of orientation-selective cells is independent of any effects of horizontal connections among V1 cells. These results could be an extension of those of Mackay and Miller (1990 *Network* **1** 257–297).

◆ **A network model for response selection in the presence of noise**

B079 M Keil, G Cristobal (Images and Vision, Instituto de Optica—CSIC, Serrano 121, E 28006 Madrid, Spain; fax: +34 91 564 5557; e-mail: mat@optica.csic.es)

For high-level visual tasks the brain has to establish robust representations of visual stimuli. But even if one triggers a given neuron several times with its optimal stimulus, the observed responses show great variability. The problem is to find a mechanism that reliably indicates the presence of a stimulus and in this way provides a robust cortical representation, eg of sensory signals. To solve this problem, population coding was suggested, making use of the fact that neuronal noise is independent in each neuron. However, Arieli et al (1996, *Science* **273** 1868) provide evidence that neuronal noise shows strong correlations across large cortical areas, rendering the responses of populations of neurons as unreliable as their individual constituents. We present experiments with a recurrent network model based on an idea of Grossberg (1989 *Neural Networks* **2** 29–51). This consists of time-dependent nonlinear differential equations simulating the membrane potential of each neuron. Noise was injected by using the logistic differential equation. In a nutshell, the model amplifies responses that exceed a threshold, consequently increasing the signal-to-noise ratio of salient or possibly important signals. We examined the conditions under which this model yields stable representations of salient stimuli in the presence of noise. Furthermore, the implications are discussed under which our model might be a solution to the initially ill-posed problem and hence would provide an alternative to population coding.

BINOCULAR VISION AND STEREO

◆ **Blur and stereoscopic disparity interactions influence depth perception**

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Photographic and retinal images of three-dimensional scenes contain regions that are spatially blurred by differing amounts, owing to depth-of-focus limitations. This blur variation offers a quantitative cue to the relative distances of points in the scene. We measured the interaction between blur and stereoscopic disparity depth cues. Observers viewed two random-dot stereograms (RDSs) in a 2AFC task, and were required to identify the RDS depicting the greatest depth. Both contained a disparate central square region of dots against a random background. In control observations, all dots in both RDSs were sharply defined: observers achieved a subjective match between them when they had physically matching disparities. In experimental observations, one RDS (comparison) contained only sharply defined dots, but the other (reference) contained differential spatial blur between the central square and the background, to introduce a blur depth cue: Observers required a larger disparity in the comparison RDS to achieve a subjective match with the reference, indicating that blur enhanced apparent depth separation. According to calculations, addition of differential blur increased the apparent depth separation between the square and the background by 33%, although only when the blur difference was consistent with the sign of disparity.

◆ **Moving dichoptic plaids exhibit the missing-fundamental illusion**

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When orthogonally oriented gratings of sufficiently high contrast are presented to opposite eyes, the image of the resultant 'dichoptic plaid' exhibits robust binocular rivalry. Nevertheless, when the gratings are set in motion, observers can reliably report the direction of motion of the dichoptic plaid [Banton et al, 1994 *Investigative Ophthalmology & Visual Science* **35**(4) 1272; Gilroy and Cobo-Lewis, 1998 *Investigative Ophthalmology & Visual Science* **39**(4) S619]. To assess whether the motion is extracted by applying feature tracking to the cyclopean image, or whether it is extracted by low-level binocular motion sensors, we constructed dichoptic plaids with one or both components consisting of a missing-fundamental grating, and set each component in four-stroke apparent motion (Adelson, 1982 *Investigative Ophthalmology & Visual Science* **22** Supplement, 144). Naive subjects indicated that the dichoptic plaids each moved in a direction consistent with the missing-fundamental illusion. This result is consistent with low-level binocular motion sensors operating on the rivalrous stimulus.

◆ **Depth perception with a stereoscopic robot head**

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TRISH-2 is a stereoscopic robot head that arose from the TRISH-1 platform. The robot consists of two computer-controlled CCD cameras acting as eyes. The cameras are mounted on motorised bases and have two extrinsic degrees of freedom. They can be independently panned (azimuth) under computer control. Torsion about the optic axis of each eye is achieved in software. The entire head can also be panned (azimuth) or tilted (elevation). Each camera provides additional optical degrees of freedom under computer control, with independent settings for focus, zoom, aperture, exposure, shutter speed, and video gain. Using TRISH-2, we investigated optimising the optical and rotational parameters for specific stereoscopic visual tasks. These techniques are often analogous to mechanisms proposed for biological vision. For example, Howard and Kaneko (1994 *Vision Research* **34** 2505–2517) proposed a modified version of the deformation theory of inclination perception. Vertical shear disparity is averaged over the binocular field and used as the vertical disparity term in computing inclination from deformation disparity. To implement this theory, we use global cyclodisparity to set the torsional position of the eyes and then use deformation disparity to compute inclination. Torsional control of the stereo head improved efficiency of stereoscopic processing and enhanced performance for computing surface structure on inclined surfaces. Other analogies to biological stereoscopic mechanisms were considered as well as algorithms with no biological counterparts.

◆ **Differences in temporal integration for binocular lustre and stereopsis**

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Earlier experiments have shown that a global figure in a random-dot stereogram is recognised when the anaglyphs are monocularly presented with a frequency down to 2.5 Hz alternately to the two eyes (Pieper, 1997 *Perception* **26** Supplement, 46). Here, we examined the influence of (1) the alternating frequency and (2) interocular delay on (a) binocular lustre and (b) stereopsis. LCD shutter glasses were used to control the viewing conditions. Subjects were instructed to press a key as long as they could perceive (i) a silvery sheen (binocular lustre) in a rivalrous three-disc display and (ii) a global figure portrayed in a stereogram. In experiment 1, monocular exposures to both eyes followed each other without pauses. Psychophysical procedures were used to determine the frequency threshold for binocular lustre and for stereopsis. A breakdown frequency of 10.1 Hz was found for binocular lustre. The breakdown frequency for stereopsis was 3 Hz. In experiment 2, alternating monocular exposures of 25 ms duration were separated by variable pauses. Stereopsis disappeared with 51 ms pauses, whereas binocular lustre disappeared with 20 ms pauses. The results show that the temporal integration for stereopsis is significantly higher than for binocular lustre.

◆ **A new type of free-fusing stereogram using binocularly unpaired wedge-shaped surfaces**

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We reported previously that there are binocularly unpaired regions in an object with a curved surface (Idesawa, 1991 *Japanese Journal of Applied Physics B* **30**(4) L751–L754) and that the

unpaired area can be perceived at nearer depth than the paired area in a random-dot stereogram (Idesawa, 1998 *Perception* **27** Supplement, 101) which is inconsistent with Julesz's hypothesis [Julesz, 1971 *Foundations of Cyclopean Perception* (Chicago: University of Chicago Press)]. The above percept is physically valid and the simplest arrangement that can be used is a wedge-shaped surface in which the edge is oriented vertically, so that the left side of the surface can be seen by the left eye only and the right side of the surface can be seen by the right eye only. By arranging multiple wedge-shaped surfaces horizontally, the whole of the visual field can be covered with binocularly unpaired regions so that the left sides of the surface can be seen by the left eye only and the right sides of the surface by the right eye only. In this way, both halves of a stereogram can be displayed in the same picture and we can fuse them without any instruments. We have created several free-fusing stereograms using this technique and investigated their perceptual consequences.

◆ **The influence of first-order information on second-order stereopsis**

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To what extent are second-order stereopsis mechanisms influenced by the nature of the first-order information 'under' the contrast envelope? For a low-contrast Gabor with a carrier oriented vertically in one eye and horizontally in the other, stereoscopic depth can be perceived at large disparities if spatial frequency is low (<1 cycle deg^{-1}). At higher spatial frequencies (2–4 cycles deg^{-1}) performance is poorer. Some studies have suggested that a preference for low carrier spatial frequencies might be influenced by the orientations of the carriers and/or the presence of an early nonlinearity (distortion product). Therefore, we measured contrast thresholds for stereoscopic depth identification (front/back) using Gabor stimuli: (1) with a 90° interocular orientation difference at a range of absolute orientations; (2) with 30° and 60° interocular orientation differences; (3) transformed nonlinearly to counteract the internally generated distortion product. Contrast thresholds for stereopsis were normalised to those for simultaneous monocular detection of the same pattern. None of these stimulus manipulations affected the normalised contrast thresholds for stereopsis. The remaining explanation is that second-order stereopsis is subserved by a variety of mechanisms with varying sensitivities to carrier spatial frequency, disparity, and envelope size.

◆ **Visual synchrony and stereovision**

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Interocular asynchrony can produce a depth illusion in dynamic noise patterns [Tyler, 1974 *Nature (London)* **250** 781–782]. We introduced temporal asynchronies in dynamic random-dot stereograms such that interocular delays of 13.4 ms were distributed randomly and evenly between the pixels of two stereo images. The effects of noise and contrast were very similar to those for conventional stereograms and we found that asynchrony did not interfere with stereopsis (logistic regression, $p > 0.1$). One possible explanation is that binocular cells restructure their receptive field to compensate for the interocular delay. If this were true, a brief view of a static stereogram would be difficult to discriminate after adaptation to asynchronous input. Subjects were asked to view either an asynchronous or a conventional dynamic stereogram for 2 s before and after a 13.4 ms exposure to a static stereogram and then make an 8AFC decision about the position of a circle during a brief stimulus presentation. We found that error rates were lower after adaptation to an asynchronous stereogram and there was a small, but significant, difference between the two groups ($p < 0.01$). These results are inconsistent with the receptive-field-restructuring hypothesis and instead suggest that the underlying neural mechanism of stereopsis is broadly tuned for temporal asynchronies between the two eyes.

◆ **Interocular velocity differences or disparity temporal changes? A unifying approach to the**
B087 detection of motion-in-depth through phase-based disparity measurements

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There are at least two binocular cues that can be used to determine the motion of an object toward or away from an observer (Harris and Watamaniuk, 1995 *Vision Research* **35** 885–896). First, the visual system might use binocular combination of monocular velocity signals. Second, the motion-in-depth signal could arise by the rate of change of retinal disparity. We suggest that, at an architectural level, both cues rely upon the same monocular measures, if a phase-based disparity

encoding scheme is assumed (Fleet et al, 1996 *Vision Research* **36** 1839–1857). In this perspective, interocular velocity differences as well as disparity measures provide the same information about motion-in-depth, when the rate of change of retinal disparity is evaluated as a total temporal derivative of the disparity. The resulting operator relies upon spatiotemporal differentials of the left and right retinal phases that can be approximated by linear filtering operations with spatiotemporal receptive fields. By using a network model, we postulate the generation of binocular motion-in-depth selective cells as a hierarchical combination of monocular spatiotemporal subunits. Relationships between these subunits and the measured properties of simple and complex cells in the visual cortex (Ohzawa et al, 1997 *NeuroReport* **8** iii–xii) are discussed. Extensive simulations of the model have been performed to validate the approach.

◆ **Neuroanatomy of binocular responses in cortical area 17 of the cat**

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Despite the availability of vast physiological and psychophysical data on binocular vision, the cortical neuronal connections which provide the binocular responses of cells have not been discovered. On the basis of the known anatomy of visual pathways we have estimated the theoretical locations of activity centres appearing in the striate cortex of both hemispheres in response to a light-spot stimulus presented in different positions in visual space. It seems that 3-D space may be divided into sectors with specific projections (2–4 cortical activity centres in one or both hemispheres) of a light spot onto the cortical map. In order to get a single percept of such an object, the linkage of several cortical activity centres is needed. We have studied the most probable basis of such integration—the intrinsic and callosal connections in area 17 of the cat. Single cortical columns were microiontophoretically injected with horseradish peroxidase. The retrogradely labelled cell regions were reconstructed in 3-D. Our data shows that cells sending axons to the single columns form some characteristic regions (as theoretically predicted) and are specific in their dimensions and location in one or both hemispheres. The cooperation of intrinsic long-range and callosal connections might provide the basis for binocular neurons with different disparities.

◆ **Human cortical areas responding to disparity. An fMRI study**

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Disparity has been shown to be an important cue for depth perception in binocular vision. In this experiment we used gradient-echo, echo-planar imaging (EPI) to identify areas in visual cortex and associated areas in temporal and parietal cortex that show BOLD contrast effects to stimuli presented dichoptically with versus without disparity. Imaging was performed with a 1.5 T whole-body Siemens Magnetom (Vision) equipped with a gradient system having 25 mT/m amplitude and 0.3 ms rise time. Sixteen 4-mm planes, positioned obliquely to the axial plane, were imaged every 4 s. with a T2*-weighted sequence (TE = 62 ms, flip angle = 90°, FOV 256×256 mm^2, 128×128 voxels). The visual stimuli were created on a VSG graphics board and shown in back-projection with an LCD-projector. Two checkerboards, one in each eye, were shifted vertically 1.5 deg every 500 ms either in phase (nondisparity condition) or out of phase (disparity condition) thus producing the impression of a checkerboard changing in depth. Initial results show that most visual areas responded to the stimuli, and the responses in some of these areas were enhanced by disparity, especially in extrastriate area 18 as well as in the precuneus and the fusiform gyrus.

◆ **Interaction of binocular and stereokinetic depth mechanisms in children**

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Using a rotating plane object with several eccentric and asymmetric annuli, one could observe an illusory depth effect. This stereokinetic effect is normally larger in monocular than in binocular viewing conditions, but in patients with certain cerebral lesions the difference is reduced or absent [in Russian, Mogilev, 1982 *Mechanisms of Spatial Vision* (Leningrad: Nauka) p. 112]. Evidently, normally developed binocular mechanisms opposed the stereokinetic mechanism responsible for the illusion. We compared magnitudes of monocular and binocular stereokinetic effects in children aged 6–8 years and in adults. Among children there was a subgroup with binocular dysfunctions. Interaction of stereokinetic and binocular mechanisms was characterised by a coefficient $K = (H_m - H_b)/H_m$, where H_m and H_b stand for depths perceived in monocular and binocular conditions, respectively. In most children without binocular anomalies and in students, stereokinetic effect appeared to be larger in monocular conditions and K-histograms had peaks around $K = +0.3$.

However, in most children with binocular anomalies, K appeared to be negative, ie stereokinetic effect was larger in binocular conditions, and the K-histogram had a peak around $K = -0.1$.

◆ **Feature-induced spatiotemporal structure in binocular rivalry**

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We studied the spatiotemporal structure of the dominance pattern in binocular rivalry induced by the presence of visual features presented monocularly to both eyes. The stimuli we used were various sets of circles moving in a homogeneous background. The properties of the circles were controlled independently for each eye. The colour of the background was used as the indicator of the dominance pattern. We found that the resulting spatiotemporal dominance pattern was strongly influenced by the monocularly presented circles. Statistical analysis of dominance pattern in the spatiotemporal domain shows a strong correlation with the spatiotemporal statistics of the moving circles. We conclude that the visual system behaves as a dynamically adaptive system which tries to maximise the information obtained from the visual scene, where the adaptability is constrained by the inherent properties of the neural process underlying binocular rivalry.

◆ **Autostereograms as a research tool in stereoscopic vision: Interactions between some cues in perception of motion-in-depth**

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We present a novel methodology for investigating stereoscopic vision, based on computer-generated static and dynamic autostereograms. It makes it easier to (i) manipulate distinct depth cues and (ii) introduce conflicts between them. To demonstrate the advantages of the methodology two experiments are described designed to examine motion-in-depth. Each dynamic autostereogram was generated as a succession of static autostereograms with elements whose disparity was modified to produce a percept of motion-in-depth. In the first experiment, all depth cues were held constant, with only the disparity varied. In the second experiment, a conflict between two depth cues, disparity and size, was introduced. Observers were required (i) to determine the direction of motion and (ii) to estimate and compare the velocities and distances travelled from distinct elements. When only disparity was changed, two effects were observed: (i) an effect of size constancy and (ii) a directional anisotropy of velocity perception—forward motion was perceived faster then backward motion. In the case of the disparity–size conflict (i) the judgments were based only on the disparity and size information was ignored, and (ii) the stability of the autostereograms was impaired. In both experiments, perceived velocity and distance increased with disparity. The results are discussed in terms of basic cue-interaction categories and in relation to the models of cue integration.

◆ **The perceived direction of motion in depth of an approaching object whose size on retina is constant**

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Human perception of motion in depth has been investigated with the use of binocular disparities. However, there is conflicting information from vergence and accommodation: disparity and viewing distance. In the present study we investigated the effects of both cues by varying them simultaneously in computer-generated displays. An approaching (or going away) white disk was shown to observers in dark surroundings. The viewing distance was changed by physically moving the display. The size of the disk in the display was controlled so as to keep its size on the retinas constant; thus there was no changing-size cue. We found that, under appropriate conditions, the observers judged the direction of the motion to be opposite to that predicted.

◆ **Monocular alignment in different depth planes**

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We examined (a) whether monocular lines with different horizontal visual directional values can appear to be aligned, and (b) whether the difference between their directional values can vary with the perceived depth between the monocular lines. In the two experiments, each of two vertical

monocular lines was presented in each of two rectangular areas in one field of a random-dot stereogram which had binocular disparities. In experiment 1, fifteen subjects were asked to align the two vertical lines in a stereogram with 10.4 min of arc crossed or uncrossed disparity. The result indicated that the mean horizontal 'gap' between the two lines was 2.6 min of arc when the lines were perceived to be aligned. In experiment 2, eleven subjects were asked to align the lines horizontally, and to report the perceived depth between the two lines and that between two rectangular areas. The results indicated that the horizontal gap between the aligned lines did not covary with the perceived depth between the two areas, whereas the perceived depth between the two lines covaried with them, suggesting that the visual direction and the perceived depth for the monocular lines are mediated via different mechanisms.

◆ **Evidence favouring eye competition during binocular rivalry**

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Does binocular rivalry involve competition between corresponding areas of the two eyes or competition between alternative perceptual interpretations? Evidence favouring both views is found in the literature. According to 'perceptual interpretation', a rival target should not necessarily be yoked to the fate of the eye that views it. To test this prediction, we determined whether a rival target in one eye was compelled to obey the temporal dynamics of a second rival target imaged in that same eye. Four observers viewed orthogonally oriented, dichoptic gratings subtending 1.7 deg × 1.7 deg. The contrast of one grating was set at three levels (0.1, 0.2, 0.4) across trials, while holding the contrast of the grating in the other eye fixed at 0.2. Superimposed on the variable-contrast grating was the image of a face, jittered over time to segregate it from the grating. Observers tracked rivalry between the two gratings or rivalry between the face and grating. As expected, predominance of the variable grating increased with the contrast. Predominance of the face increased too, even though its contrast was invariant, as predicted by the eye-competition hypothesis. Evidently, rivalry cannot select different objects for dominance and suppression.
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◆ **Can the magnitude of the binocular depth contrast effect be predicted solely by the induction of disparity information?**

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We propose that the binocular depth contrast effect (BDC) is not simply due to disparity induction. Rather, BDC is effected by retinal orientation and binocular disparity information. Parallel pitched lines produce bilaterally symmetric retinal image orientations. For example, topforward pitched lines in the RVF (LVF) produce clockwise (anticlockwise) rolled retinal images. If BDC were based solely on roll induction, the sign of induction would change when the test line crossed the median plane; if BDC were based solely on disparity induction, the sign of induction would not change. Four subjects set the pitch of a plane containing a luminous test line to appear erect in the presence of a variably pitched luminous induction line. The T-line and I-line were either on the same or opposite sides of the median plane. In the same-side condition, settings of the T-line varied directly with I-line pitch. In the opposite-side condition, T-line settings did not vary with I-line pitch. A combination of influences from disparity and retinal orientation explains both results. Thus, in the same-side condition, disparity induction and roll induction have the same sign and generate a substantial effect; but in the opposite-side condition, the two sources conflict, and their effects cancel.

◆ **Accommodation cues reduce latencies for large-disparity detection**

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Current head-mounted displays and laboratory Wheatstone stereoscopes use binocular disparities to simulate three-dimensional scenes, but present the observer with conflicting accommodation cues. We have developed a binocular instrument that can display multiple virtual depth planes and so provide appropriate vergence (disparity) and accommodation (blur) cues. Here we show that the presence of appropriate blur cues reduces latencies for detecting large disparities. The stimuli were random-dot stereograms and subjects' task was to detect whether a 5 min disparate square (1.2 deg × 1.2 deg) was in front of a central disc (4.5 deg diameter) which had a pedestal disparity of up to ±5 deg with respect to the fixation plane at 50 cm (2 dioptres).

In the 'consistent' condition, all parts of the stimuli had appropriate blur cues; while in a 'conflict' condition all parts of the stimuli had a fixed blur cue of 2 dioptres. For exposure duration less than 400 ms, performance was similar under the two conditions, but for longer exposures, performance was significantly better for the large disparity pedestals in the 'consistent' condition. This improvement can be linked to accommodative vergence, which acts to bring the large disparities within detection range.

◆ **Stereoscopic detection and segregation of noisy transparent surfaces**

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Random-dot stereograms depicting multiple transparent surfaces, lying at different depths, produce complex problems for the visual system. We investigated the perception of stereoscopic transparency with and without horizontal disparity noise. Stereoscopic displays depicted a surface with horizontally oriented sinusoidal depth corrugations lying in front of, coplanar with, or behind a frontal plane surface. Gaussian-distributed disparity noise (standard deviations of 0, 2, 4, or 8 min of arc) was added to dots representing the sinusoid. In different conditions, subjects reported: (1) whether they saw the sinusoid or not (surface detection); (2) whether they saw both the plane and the sinusoid or not (surface segregation). While detection of the sinusoid was quite robust in the presence of substantial disparity noise (eg up to 2–4 min of arc), surface segregation degraded quickly. The depth order of the two transparent surfaces was important for surface segregation, which was achieved more readily when the plane was located in front of the sinusoid than when it was beyond or bisecting the sinusoid. The processes involved in segregating transparent surfaces would appear to be particularly susceptible to disparity noise—presumably owing to difficulties in distinguishing disparity discontinuities produced by transparency from those produced by noise.

CONTRAST

◆ **Pedestal effects with periodic pulse trains**

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It is important to know how performance varies with stimulus contrast. But retinal contrast is limited by the modulation transfer function of the eye; an 8 cycles deg^{-1} grating with 90% contrast corresponds to a retinal image with 45% contrast. More contrast is required to discriminate between theories of contrast discrimination (Wichmann et al, 1998 *Perception* **27** Supplement, 86). The stimulus with the greatest contrast in any component is a periodic pulse train with 200% contrast at every harmonic. Such a waveform cannot be produced; the best with our Mitsubishi display has 150% contrast at an 8 cycles deg^{-1} fundamental, producing a retinal contrast of about 75%. The penalty for using this stimulus is that the second harmonic of the retinal image also has high contrast (more than 60% of the contrast of the 8 cycles deg^{-1} fundamental). We have used standard 2AFC experiments to measure the detectability of an 8 cycles deg^{-1} pulse train against the background of an identical pulse train of different contrasts. An unusually large improvement in detectability was measured — the pedestal effect or 'dipper'—and the dipper was unusually broad. The implications of these results are discussed.

◆ **A broad band of spatial frequencies contributes to suprathreshold perceived contrast**

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It is well known that, for sinusoidal gratings, contrast thresholds depend on spatial frequency, but suprathreshold contrast perception exhibits contrast constancy, ie contrast matches are independent of spatial frequency at high contrast levels. We studied whether contrast constancy applies to complex spatial stimuli of different spatial-frequency bandwidths. Contrast thresholds were measured and contrast matching was performed for two-dimensional spatial noise stimuli. The spatial-frequency band was centred at 2 cycles deg^{-1}. The bandwidths ranged from 0.25 to 8 octaves. Contrast thresholds and contrast matching curves at low contrasts increased as spatial-frequency bandwidth increased beyond 1 octave. At high contrast levels, however, contrast matches were nearly independent of stimulus bandwidth up to about 6 octaves. Thus, the spatial-frequency bandwidth of perceived contrast was broad. These findings show that contrast constancy with respect to spatial frequency also applies to complex stimuli, and that contrast information is integrated across spatial frequencies so that the effective bandwidth of the system is broad at high contrast levels.

◆ **Perceived contrast and contextual effects**

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The perceived contrast between two surfaces with different luminances is affected by all the perceptual attributes of the stimulus (Helson and Rohles, 1959 *American Journal of Psychology* **72** 530–538). In the experiment, I used three pairs of chips, with different luminance contrasts. There were four series of stimuli. In series I and II adjacent or separate chips, respectively, were presented on a homogeneous background with three different luminances; in series III and IV, adjacent or separate chips, respectively, were presented on a bipartite background. Series III and IV were presented once with constant luminance of both parts of background for all the pairs of chips, and once with varying luminance of left part of the background. Participants rated the degree of contrast using integers from 0 (absence of contrast) to 100 (black vs white). Separate ANOVAs for each series showed that the perceived contrast was affected by background luminance only in stimuli of series II. Stimuli of series III produced a transparent figure seen on a bipartite background. An overall ANOVA for series I and III showed that transparency reduced the perceived contrast between the chips. For stimuli of series II and IV, the perceived contrast was reduced. This result agrees with Diamond's (1955, *Journal of Experimental Psychology* **50** 144–152) findings that contrast effect decreases as distance increases.

◆ **Delay in processing high-spatial-frequency signals and local retinal stimulus intensity**

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Reaction time (RT) and the latency of visually evoked potential (VEP) are delayed at increasing grating spatial frequency (SF). Saleh and Bonnet (Fechner Day 98, ISP, Quebec) have found that the contrast × grating-period product, $C \times P$ ('local intensity of stimulation'), rather than SF per se determine RT. The highest SF in their experiments was 6.5 cycles deg^{-1}. In the present experiments their findings have been checked over a wider SF range and for VEP latency as well. RT and VEP were recorded to the onset of sinusoidal gratings. Grating SF varied from 0.5 to 16 cycles deg^{-1} and the contrast varied from near threshold to 50%. Stimulus nominal contrast was corrected for the optical transfer functions of the eye and monitor and then multiplied by grating period. When plotted against this product, VEP latencies for all SFs tested converged on a single declining function and so did RTs up to 5 cycles deg^{-1}. At higher SF, the RT/$C \times P$ functions were systematically shifted towards longer RT. The results suggest that the central delay in processing high SFs, described by us earlier (Mihaylova et al, 1999 *Vision Research* **39** 699–705), differs markedly from the peripheral one in its dependence on local intensity of stimulation.

◆ **The time-course of contrast adaptation and recovery**

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Perceived contrast reduces monotonically as a function of adaptation duration. We measured the time-course of the reduction in perceived contrast and recovery from adaptation using the 'method of a thousand PESTs'. The perceived contrast of counterphase sinusoidal gratings (4 Hz and 16Hz, 1 cycle deg^{-1}) was measured with a forced-choice protocol after 8, 16, 32, or 64 s adaptation to a pattern with identical spatiotemporal characteristics. Perceived contrast was measured at intervals (0.1–32 s) after the cessation of adaptation. The reduction in perceived contrast was most profound after adaptation to high temporal frequencies and after long adaptation durations. At 4 Hz perceived contrast was reduced by around 10% after 64 s adaptation whereas at 16 Hz, perceived contrast was typically reduced by around 40%. This decay in perceived contrast was well-modelled by a single exponential function. However, the subsequent recovery from adaptation could not be modelled successfully by any single function. Recovery functions for different adaptation durations exhibited differences in both the slope and the time constant of recovery. We posit that these shifts in slope and time course for recovery from adaptation may reflect the operation of two underlying processes of recovery, one additive and one divisive.

◆ **Achromatic and chromatic contrast channels of human spatial vision and their combination at detection threshold**

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Cone contrast signals (C_s, C_m, and C_l) are combined to an achromatic channel (C_a) and two chromatic channels (red–green, C_{rg} and blue–yellow, C_{by}). Using channel specific signals and cone specific noises we have previously shown that $C_a = (0.077C_s + 0.211C_m + 0.712C_l)$,

$C_{rg} = 2.97(C_m - C_l)$ and $C_{by} = (0.619C_s - 0.338C_m - 0.281C_l)$. To test a model where the channels are at detection threshold combined as $C_{th}^n = |C_a|^n + |C_{rg}|^n + |C_{by}|^n$, where $|C| = \text{abs}(C)$, we used red, green, blue, and achromatic gratings, gratings with equal phase and contrast ratio of 1 : 1 or 1 : 3 in two phosphors and gratings with phase angle difference of 180° and modulation amplitude ratio of 1 : 1 or 1 : 3 in two phosphors, and expressed thresholds in Vos–Walraven cone contrasts. The fit of the model to experimental results was excellent ($\chi^2 = 0.0022$) when $n = 4$, $C_a = (0.052C_s + 0.215C_m + 0.733C_l)$, $C_{rg} = 1.39(C_m - C_l)$ and $C_{by} = 0.359(C_s - C_l)$ but it was almost as good although $n = 3 - 5$ or C_{by} was based on $C_s - (C_m + C_l)/2$ or $C_s - C_m$. The result means that detection threshold is determined by the channel with highest contrast.

ATTENTION AND SEARCH

◆ **Within-object conjunction visual search: evidence for grouping and binding before and after practice**

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It has been suggested that within-object conjunction search can be parallel and preattentive provided that feature binding (by specific junction detectors) and nontarget grouping (based on regularity) occur. We tested the binding hypothesis by investigating the time course of learning in visual search for conjunction of features. Two learning sessions (10 and 5 blocks each) took place three months apart. Results show that: (i) in within-object conjunction (inverted V among upright Vs) but not in across-object conjunction search (red among green and red), learning endured from one session to the other, suggesting that it is located at an early level of processing in the central visual system; (ii) this enduring effect in within-object conjunction disappeared when both target and distractors were rotated to modify their absolute but not their relative orientations, as predicted by the binding hypothesis. We tested the grouping hypothesis in two ways. In perceptual learning experiments we showed that the enduring effect disappears when collinearity is perturbed. In standard psychophysical experiments we showed that temporal thresholds (stimulus duration for 75% correct), measured independently for 'present' and 'absent' target conditions as a function of background numerosity (4 to 64 elements), increase in within-object conjunctions and decrease in simple search when collinearity is perturbed.

◆ **Mirror-image distractors and visual search: what do they reveal about perceptual processes?**

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Perceptual processing of symmetric objects and features can occur quickly and effortlessly, especially for mirror-image symmetry. But, sometimes mirror-image symmetry can hurt rather than help. For instance, visual-search performance may be worse when distractors are mirror-images of the target than when they are not. Specifically, we investigated how mirror-image distractors affected (i) target-distractor discriminability, (ii) attention sharing, (iii) accuracy of target detection, (iv) confusions about spatial location of the target, and (v) whether noise or some other explanation could explain the set-size effects. We determined accuracy of target detection and localisation performance both when a Landolt C target was embedded among backward Cs (mirror-image condition) and when the target was embedded among Os (simple feature condition). Target-distractor discriminability was equated in both search conditions and the relevant set size was either 2 or 4. Mirror-image search performance is often worse than simple feature search, but not always. Overall, mirror-distractors do not affect target-distractor discriminability or the ability to share attention across locations. But, compared to simple feature search, mirror-image search resulted in larger set-size effects, caused greater spatial confusions about target location, and yielded search performance that was inconsistent with a purely noise-based model. Implications are discussed.

◆ **Attention and processing of visual orientation**

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When an upright inner square is added to an outer tilted square, their combined influence on the perceived orientation of a central rod is in the opposite direction to the effect obtained with a single tilted inducing frame. Zoccolotti et al (1997 *Perception* **26** 1485–1494) discussed this double-frame effect in terms of Rock's hierarchical organisation principle. We propose an attentional explanation of the hierarchical organisation effect. Two experiments were performed with a double frame inducer changing goal-driven attention in order to compare a direct measure of

frame influence with an indirect measure of unattended processing. In one experiment two different conditions were tested: a direct rod judgement and an indirect inner-frame measure. Both conditions showed the same angular function but the effects were in opposite directions. In the second experiment an indirect inner-frame measure was compared to a direct measure of it. Two different results were obtained in terms of the shape of the angular function and of the amplitude and direction of the effects. These results are consistent with an explanation of the reference frame and hierarchical frame in terms of different processing depending on the focus of attention.

◆ **Preattentive processing in a preattentive task**

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Joseph et al [1997 *Nature (London)* **387** 805–807] suggested that attention is required for the detection of orientation, a feature usually considered to be detected preattentively. They required subjects to identify small, briefly presented letters at the centre of gaze and simultaneously, or with a short delay, to detect the presence/absence of an odd orientation, presented 5.3 deg from fixation. Subjects were impaired at detection of the odd orientation when presented within 400 ms after the presentation of the target letter; thus Joseph et al concluded that detection of orientation is attentive. It may be the case, however, that this demonstration of attention in preattentive vision is limited to cases in which the feature to be detected shares features with the centrally presented target. We repeated Joseph et al's paradigm but required subjects to detect an odd colour rather than orientation. In this case the detection was effortless and unaffected by the effortful letter identification task. We also established that under some conditions subjects could perform an orientation task without any interference from the letter tasks. We conclude that the original report described effects related to task difficulty or attribute independence.

◆ **The explicit and implicit in visual awareness**

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Currently there are two seemingly conflicting lines of thought for the neural correlates of visual awareness. Crick and Koch [1995 *Nature (London)* **375** 121–123] put forward the view that only neural activities in those visual areas directly connected with the prefrontal cortex correlate with visual awareness. Their model seems to be supported by evidence on the neural correlates of dominance shift in binocular rivalry (Tononi et al, 1998 *Trends in Cognitive Sciences* **2** 474–484; Logothetis, 1998 *Current Opinion in Neurobiology* **8** 536–544; Lumer et al, 1998 *Science* **280** 1930–1934). On the other hand, the neurology of blindsight (Weiskrantz et al, 1995 *Proceedings of the National Academy of Sciences of the USA* **92** 6122–6126) implies that the loss of V1 results in a loss of visual awareness. This loss indicates a central role of V1 in visual awareness. I propose a systems-oriented model of visual awareness in which the conflicts between these two views on visual awareness are dissolved. In this model, the explicit representation in higher visual areas act as 'pointers' to the qualia, which constitute the visual features. In turn, these correlate with the cluster of neural firings starting from the area V1. The differentiation of pointers and qualia gives new insights into the coordination of multiple cortical areas in visual perception.

◆ **Orientation asymmetry in target detection with isoluminant red–green stimuli**

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With luminance-defined stimuli, detection of a tilted target among vertical distractors is easier than detection of a vertical target among tilted distractors. Is this orientation asymmetry found with isoluminant stimuli? In a target-detection experiment with briefly presented stimuli, displays comprised ten elliptical elements, with major and minor axes of length 1.0 deg and 0.25 deg respectively, within a circular area of diameter 20 deg. A target appeared with probability 0.5, and was either vertical and among distractors at 20° to the vertical, or at 20° to the vertical and among vertical distractors. In target-absent displays, elements were either all vertical or all at 20° to the vertical. The elements were either red on an isoluminant green background or dark-grey on a light-grey background. Red–green and luminance-defined stimuli had identical cone contrast. Target-detection performance (proportion correct) was poorer with isoluminant than with luminance-defined stimuli (the isoluminant stimuli were also the least detectable at low cone contrast), and the orientation asymmetry was significant with both isoluminant and luminance-defined stimuli. It appears that mechanisms of rapid orientation-processing operate more effectively with luminance-defined than with isoluminant stimuli, and the orientation asymmetry arises from a mechanism operating on both chromatic and luminance information.

◆ **Distribution and allocation of visual attention**

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Prolonged steady viewing of an adaptation figure causes an apparent position shift of a spatially displaced test figure. Yeh et al (1996 *Journal of Experimental Psychology: Human Perception and Performance* **22** 446–460) have shown that such figural aftereffect (FAE) is modulated by spatial attention. A new paradigm was then developed to examine the distribution of visual attention by combining the attention task and the FAE task. In four experiments, attention was manipulated by counting digits while the subject adapted to two counterphasing Gaussian blobs. The number of digits ranged from 1 to 4, and the relative locations of the digit(s) and the adaptation blobs were changed to test the specific hypothesis posited in each experiment. After adaptation, subjects judged the relative position of two test blobs. The magnitude of the FAE was measured by the apparent position shift of the two test blobs, which, in turn, served as an index of the distribution and magnitude of attention. The results rule out the possibilities that the span of attention is of restricted and specific shape and that one's attention can be narrowly focused on nonadjacent locations. Perceptual load affects the magnitude and distribution of visual attention.

◆ **Search strategies based on codification of the relational properties of the stimuli**

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In a previous presentation (Sampedro et al, 1998 *Perception* **27** Supplement, 67) we described results showing efficient search for stimuli defined by a within-dimension conjunction of colour × colour when their parts were in different spatial planes (the target was a red square over a green square and each distractor was a green square over a red square). In the present work we continued that investigation and we explored three explanations of these results. (i) Subjects may segregate the information contained in the closer plane and search only for the parts of the elements contained in this plane. Here the task would be a search for the red part of the target among the green parts of the distractors. (ii) The subjects may search for a specific property (the only complete red square). (iii) The emergent property associated with the spatial plane may facilitate the use of two different 'preattentive object files' for target and distractor. Our data allow us to reject the two first explanations and are consistent with the last one. We suggest an interpretation in the context of Wolfe's guided search model, that will be extended to other kinds of stimulus configurations.

◆ **Pauses in RSVP text improve comprehension for learning disabled and normal readers**

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Previously, we [Heidenreich et al, 1998 *Investigative Ophthalmology & Visual Science* **39**(4) 178] compared reading comprehension for learning disabled and normal readers given adult-level text displayed in a rapid serial visual presentation (RSVP). The results showed that reading rates for RSVP text were approximately 1.5 times faster than reading speeds for full-page text. Comprehension scores were significantly higher with the RSVP format for learning disabled readers and comparable for normal readers. Given that a speed–comprehension trade-off occurs as RSVP speeds increase, we tested in the present study whether comprehension would improve when pauses were inserted after commas (intrasentence) and after final punctuation (intersentence). To create intrasentence pauses, commas were added to the text when grammatically appropriate. Pause duration and RSVP rate were factorially manipulated. Learning disabled college students and those with no reading disability silently read excerpts selected from adult-level, standardised reading comprehension tests and answered multiple-choice questions after each passage. Comprehension was significantly better with slower RSVP speeds. However, comprehension scores differed for similar presentation rates: pause duration was the critical factor, rather than the average word-per-minute speed. Results are interpreted in terms of the time constraint for conceptual processing.

◆ **Perceptual priming is asymmetric with and without attention**

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Object recognition can be approached as a process of disambiguation. This implies asymmetric visual processing. A series of priming studies was performed to establish whether perceptual priming reflects this asymmetry and whether attention can modulate it. In one study, observers performed a same–different matching task. Stimuli consisted of familiar shapes rendered as

outlines and surfaces. The key manipulation was whether the preceding trial contained more or less ambiguous renditions of the same stimulus. In another study, displays consisted of two overlapping novel shapes and a target shape. Observers reported whether the cued shape matched the target shape. Following a negative priming paradigm on half of the trials, the unattended shape from one trial became the attended shape on the subsequent trial. Judgments were speeded when more ambiguous renditions were displayed before less ambiguous renditions of the same shapes. Judgments were not speeded with reversed display orders. This pattern of results held under conditions of attention and inattention. Asymmetric perceptual priming may reflect the directionality of visual processing. Phenomena, found in the priming literature, such as increased priming with increased similarity, should be considered within the context of visual processing constraints.

PERCEPTUAL ORGANISATION

◆ Effects of orientation difference on texture segregation in the central visual field

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Texture segregation sensitivity drops in the fovea. This effect, first reported by Kehrer (1987 *Spatial Vision* **2** 247–261), is called central performance drop, CPD. Sekine and Kikuchi (1995 *Perception* **24** Supplement, 121) found similar results using textured regions made up of T and L elements. The aim of the present study was to investigate whether the relative orientation of texture elements affects the CPD. Participants were asked to detect a target texture (6 deg wide, 6 deg high) embedded in a large background texture (82 deg wide, 76 deg high). In experiment 1, the difference between target and background element orientation was 30°, 60°, or 90°. As the orientation difference increased, detection performance improved. In experiment 2, additional line elements oriented 90° relative to background elements were added to both target and background textures. In these circumstances, discrimination became more difficult. CPD was found in experiment 2, but not in experiment 1. This suggests that Sekine and Kikuchi's results may be related to spatial masking.

◆ Detection of rotational symmetry and effect of closure

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It is known that in a detection task the type of symmetry to be detected (reflection vs translation) interacts with the type of display (closed vs open contours). The advantage for closed contours found with reflection is believed to be a general within-object advantage, whilst the advantage for open contours found with translation is an exception, described as a lock-and-key process (Bertamini et al, 1997 *Acta Psychologica* **95** 119–140). Using a reaction-time task, we have tested a different type of symmetry, centric or rotational symmetry, and found the same result as for translation. This finding makes the lock-and-key process more general. The effect of angle of rotation points to a similarity with mental rotation, but the location along the contour of the centre of rotation and a blocked design were not critical for finding an advantage for open contours. We suggest that this advantage is the result of an obligatory assignment of a representation based on bilateral symmetry for closed contours.

◆ Evidence for association field revealed by Ternus displays composed of Gabor elements

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A Ternus display composed of a trio of Gabor patches was used to explore how orientation information affects perception of 'group' versus 'element' motion. Displays were displaced horizontally to and fro over a range of interframe intervals (IFIs) and the percentage of perceived group motion was measured. All conditions showed increasing group motion as a function of IFI, as defined by 50% points of best-fitting Weibulls. Group motion was stronger for horizontal (ie collinear) than for vertical (ie parallel) Gabor patches, for higher spatial frequencies (7.5 versus 3.75 cycles deg^{-1}), and for elements in same phase (relative to alternating phase). Group motion varied with contrast in an elbowed function. Low contrast (11%) produced strong global motion. Global motion was much weaker at 23% contrast, but became progressively stronger at 45% and 90%. Global motion decreased as spatial separation between Gabor elements increased, especially when element orientation was not collinear. Similarly, global motion decreased with the addition of orientation jitter to the Gabor elements, but less so for collinear stimuli. These results are broadly consistent with 'association fields' used to explain contour integration in psychophysics, and with their presumed neurophysiological basis in lateral connections between orientation columns.

◆ **Can segmentation processes be modulated at an early level in visual perception?**

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We examined whether the processing of line endings involved in figure–ground segmentation can be modulated across time at an early level of visual processing. Stimuli were either two collinear segments separated by a right or left gap, or two parallel segments closed on one side. Subjects decided whether the stimuli included a discontinuity right or left. When collinear lines were displayed immediately after parallel lines, or immediately before, RTs were higher when the discontinuity was on the same side in the two successive stimuli than when it was on opposite sides. This occurred only when the two consecutive stimuli shared the same orientation. Control experiments showed that the results could not be explained by a difference in the global shape of the two successive stimuli. There was no effect of collinearity. In contrast, manipulating the alignment of parallel segments affected the results, suggesting a role of the virtual lines produced when line endings are aligned. Overall, these results suggest that segmentation processes are modulated across short amounts of time by varying the processing of line endings or the production of virtual lines.

◆ **The effects of the visual properties of diagrams in analogical problem solving**

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Three experiments were performed to examine the impact of visual properties on the effectiveness of diagrams in analogical problem solving (Gick and Holyoak, 1983 *Cognitive Psychology* **15** 1–28; Beveridge and Parkins, 1987 *Memory and Cognition* **15** 230–237), with the use of variants of 'convergence' diagrams as source analogues for Duncker's radiation problem (1945 *Psychological Monographs* **270**). Static diagrams representing the initial problematic state (one large line directed at a target) and the final state for a convergence solution (multiple converging lines) were not accessed spontaneously, but were often used successfully once a hint to consider the diagram had been provided. The inaccessibility of static diagrams was not alleviated by adding additional diagrams to represent intermediate states (experiment 1), but spontaneous retrieval and noticing were improved by animating the display to represent converging forces, and thereby encouraging encoding of the lines as indicating motion toward a target (experiments 2 and 3). However, neither static nor animated diagrams were effective when the arrows were reversed to imply divergence rather than convergence (experiment 2). The results indicate that animation can greatly enhance analogical transfer.

◆ **Dimensions of visual Gestalt: the quantitative approach**

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Our study aimed at identifying the main subjective dimensions of visual Gestalten. Two sets of stimuli were constructed and selected in order to be representative of a wide spectrum of visual Gestalten. Two groups of subjects (A and B) were then asked to judge these stimuli by marking the appropriate grade on sixty-five bipolar seven-step scales. Adjectives with opposite meaning defined the poles of scales. The scales were selected in previous studies. Group A judged the stimuli from set one, and group B judged the stimuli from the other set. A factor analysis with orthoblique rotation for the sets of stimuli (groups A and B) was performed. The 3-D matrices (stimuli × scales × subjects) were transformed into 2-D matrices by the stringing out method. The obtained factor patterns for groups A and B were quantitatively compared. The canonical coefficient demonstrated a high degree of correlation between the factors of groups A and B. The following common A and B factors were obtained: Evaluation (composed of Hedonic tone and Interestingness), Regularity, Potency, and Activity. These factors can be taken as a basis for the quantitative definition of phenomenological dimensions of visual Gestalten.

◆ **Hierarchical numerosity perception**

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The stimuli consisted of dots grouped by proximity into clusters. The numbers of dots (1–5) and clusters (1–8) were varied independently. Three participants estimated the number of dots and clusters on the basis of a randomly occurring cue across trials. Overestimation occurred for single dots and clusters while underestimation was found for the maximum number of these

elements, suggesting responses were scaled to the range of numbers used. There was also an effect of number of preceding same cues. Responses preceded by four or five trials of the same type (ie four cluster trials preceding a final cluster trial) showed increased accuracy. These results are expected if repeated trials of the same type 'set' an attentional zoom lens to either a global or local level.

◆ **Gestalt laws in perturbed spatial structures**

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Visual perception in a natural context operates on an optic field that consists neither of a random luminance distribution nor of a rigidly structured pattern. Spontaneous structure is stochastic rather than exact. In an experimental procedure designed to simulate degradation of regularity, we used dot lattices (dot fields in which the elements appear in evenly spaced rows) as our canonical regular stimuli. To degrade regularity we varied the position of each dot according to a normal density function centred on the corresponding location in the dot lattice. Using this technique we investigated the effect of stochastic perturbation on perceptual organisation. The perceptual grouping that occurs in unperturbed dot lattices obeys a firmly established quantitative pure distance law (Kubovy et al, 1998 *Cognitive Psychology* **35** 71–98). In the present experiments, we asked observers to indicate the orientation of grouping perceived in perturbed dot lattices presented for 300 ms. Our data show that the greatest effect of the degradation of regularity is due to a loss of collinearity. The results are considered in terms of the pure distance law, the interaction between Gestalt laws, and the relation between perceptual organisation and detection.

◆ **Splitting words shows they are 'spacial'**

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Current research on word perception and reading tends to ignore spatial information processing despite the fact that reading is a spatial activity. Here perceived word length was investigated with a bisection task familiar from neuropsychology. Subjects determined the perceived middle of visually presented words and lines. Bisection errors indicated an over-representation of the side toward which the subject erred. There was (1) a systematic bisection bias toward the beginning of words that (2) increased with number of characters but not with physical word length. This word bisection error was (3) not predictable from line bisection performance, was (4) not affected by an attention manipulation, (5) reversed when lexical access was manipulated, and (6) was sensitive to phoneme distribution. These results have implications for our understanding of reading: (1) word length is represented functionally, not veridically; (2) there may be a representational contribution to eye-movement control in reading; and (3) phoneme activation in skilled reading is obligatory.

◆ **Detection thresholds for brief pulses presented on dynamic backgrounds can be explained**

B124 **by a model that relates to retinal physiology**
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The temporal behaviour of detection thresholds for brief test stimuli presented on dynamic backgrounds can be quite complex. (i) After increment steps of the background intensity, prolonged threshold elevations are observed. (ii) Thresholds briefly become very high for test presentations near the moment of occurrence of background steps. (iii) For backgrounds with sinusoidally modulated intensities, test thresholds are maximal during the upswing of the background intensity for a wide range (about 0.5–10 Hz) of background modulation frequencies. (iv) For modulated backgrounds, test thresholds are elevated throughout the background modulation cycle. Here we present a physiologically realistic model that yields quantitative explanations of these measurements. The model consists of a sequence of three adaptation processes: a divisive light adaptation, a subtractive light adaptation, and a (fast) contrast gain control. Both the divisive and the subtractive processes are followed by saturating nonlinearities, which describe the finite dynamic range of the visual system. Saturation at the first nonlinearity explains the prolonged elevations of thresholds after background increment steps (i), whereas saturation at the second nonlinearity explains threshold dynamics for tests on modulated backgrounds (iii). Threshold elevations (ii) and (iv) are explained through the contrast gain control process, which is implemented such that it can produce both strong peaks (ii) and sustained elevations (iv) of the gain signal.

◆ **Quantitative evaluation of interval changes from a sequence of medical images**

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Quantitative analysis of interval changes in a sequence of time-varying images is of major interest to medical science because visual perception often cannot detect subtle differences between complex textured images. We describe a new algorithm to detect interval changes which is useful when the registration-based and subtraction-based methods do not give satisfactory results. The method is based on a previously proposed pattern histogram method and on a time series analysis technique. First, sequences of images are compared in a multidimensional pattern–vector space by using their pattern histograms to extract all potentially changing patterns. Then, time series histogram bins are modeled with an autoregressive model and a classification tree is designed to identify real abnormality variations. A sequence of 16 chest radiographs, showing an increasing number of small opacities from a single patient has been used to test the method. The images were acquired during periodical medical examinations throughout 33 years and the performance of the method is evaluated. Quantitative values of the interval changes are assessed and displayed as a diagram for the purpose of long-term patient monitoring.

◆ **Separate coding systems for categorical and metric visuospatial information**

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The existence of two qualitatively different computational processes coding and manipulating respectively categorical and metric visuospatial information has been hypothesised in a computational model (Kosslyn et al, 1992 *Journal of Experimental Psychology: Human Perception and Performance* **18** 562–577). We present data in support of this hypothesis. Subjects had to judge the physical identity of two stimuli presented in sequence. The stimulus was made up of a dot randomly placed within an oriented frame. Two successively presented frames could be rotated with respect to one another. A point in the second frame could occupy five different positions: P0 was identical to the position of the first frame, P1 and P2 were in random directions respectively 10 and 20 pixels away from P0 within the same quadrant, while P3 and P4 were in different quadrants. In different experiments we manipulated which of the two frames was rotated together with the amount of rotation between them. The data show significant differential effects on the two classes of stimuli (P0, P1, P2; and P3, P4) depending on the experimental conditions. The results are not simply explicable in terms of a single distance measure. Instead, they fit with the existence of two separate coding systems as suggested by Kosslyn.

◆ **Prior stimuli affect both size threshold and decision time**

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In an attempt to understand the encoding and retrieval processes in size discrimination, we examined discrimination thresholds and decision time (DT) as a function of prior stimulus (PS), with interstimulus interval (ISI) as parameter. For short ISIs (0.05 and 0.2 s), PS did not affect the discrimination threshold. For the 2-s ISI, PS affected both the discrimination threshold and the DT. When PS is much smaller than the reference, DT is about 50–100 ms less for judging the difference between the reference and smaller test stimuli than for judging the difference between the reference and bigger test stimuli. If the PS is at least as big as the reference, the DT is longer for judging the difference between the reference and smaller test stimuli, than between the reference and bigger test stimuli. The improvement in threshold and reduction in DT that only occur at the 2-s ISI appear to be retrieval rather than encoding effects. Within a hierarchical framework of memory systems, the relevant level would seem to be the short-term visual memory. The result implies that the content of this memory can help with judgments about more recent stimuli.

◆ **A typology of conjoint growth processes**

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A typology of perceptual and/or motor decisions on the basis of conjunction of two attributes that are made during programming of saccadic eye movements or visual search is presented. It is assumed that the processing of two conjoint stimulus attributes or dimensions of an intentional movement can be represented by two separate (linear) growth processes. The decision is made when

both the growth processes have reached a constant threshold activation level. The rate at which neural activity grows towards the threshold level depends upon whether these two growth processes are taking place simultaneously or sequentially. The analysis of the conjoint growth processes in the temporal disassociation paradigm, in which either of the two attributes is presented before the other, revealed the existence of characteristic response-time signatures on which basis a particular type of interaction between these two growth processes can be identified. For example, an approximately constant level of one of two arms of the response function is a specific sign of ordered processes: processing of one stimulus attribute cannot begin before the other. The lack of a salient maximum of reaction-time function at the zero interstimulus interval is an indication of independence of the two growth processes, but the height of the maximum, provided it is present, is a measure of interdependence.

◆ **B129 The effects of background and sound-source location upon auditory facilitation of visual-target acquisition**

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Irrelevant sound facilitates acquisition of visual targets within the central region of the visual field (Perrott et al, 1990 *Perception & Psychophysics* **48** 214–226). We examined the effects of background and task demands upon auditory facilitation. Target and distractor stimuli consisted of red or green, horizontal or vertical rectangles: the target could be differentiated from the distractors because of its relatively late onset. Targets were presented alone or were simultaneous with a noise burst from the target location or the fixation point. Stimulus duration was limited to 150 ms to preclude overt orienting. Observers reported target presence or performed a 2AFC discrimination task based upon target orientation or its combination of colour and orientation. Within all three tasks, visual baseline performance and auditory facilitation was similar for targets in empty and cluttered visual fields. Auditory facilitation was modified by task demands but there was no effect of sound-source location. Previously simultaneous, spatially congruent sound facilitated covert orienting to nonsalient visual targets (Doyle and Snowden, 1998 *Perception* **27** Supplement, 134). Target salience may have modified the effects of irrelevant sound upon visual covert orienting.

◆ **B130 Cuts and phenomenal continuity: the role of apparent motion**

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The impression of phenomenal continuity of simple animations involving two objects and undergoing an abrupt change in size (as in the film-editing practice of cutting from a long shot to a close-up or vice versa) was rated by naïve subjects. The depicted objects could either meet at a point or part from that point in opposite directions. The impression of continuity of the event (the presence or absence of a 'jump' backwards or forwards in time) was strongly influenced by the interaction between the kind of cut (from long shot to close-up or vice versa) and the direction of motion inherent to the kind of event displayed (collision or parting of the objects in the animated sequence). The results suggest a critical role of apparent motion in the perception of continuity of edited cinematic events but leave the door open to a high-order thresholded compensation of Korte's laws to allow spatiotemporal continuity to be perceived.

◆ **B131 Perception, language, and gesture: towards a natural human–computer interaction**

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Multimodal systems extract and convey meanings through different I/O interfaces, such as voice, writing, gestures, gaze movements, and facial expressions. Increasing the communication bandwidth between humans and computers, current technology has the potential of introducing a major shift in the usability of future systems: the interaction becomes more natural, flexible, and robust. The visual/spatial domain is the ideal ground for multimodal systems. Referring to objects in space is strongly simplified by the synergistic usage of natural language and gestures. Despite the importance of visual cues to resolve ambiguities, traditional multimodal interfaces are blind. References are resolved mainly by considering the dialogue context. To match spontaneous user behaviour, we propose an architecture in which gesture recognition depends on anthropomorphic perceptual features. The ecological validity of our approach is confirmed by results from a 'Wizard of Oz' experiment. Users communicated with a simulated multimodal system and moved groups of objects into appropriate boxes. Speech was mediated by a microphone and gestures by an electronic pen.

Visual-field organisation was manipulated according to Gestalt principles. Two conditions were tested: high vs low group salience. Results showed that both gesture trajectories and linguistic behaviour are influenced by perceptual-field organisation.

◆ **ShowTime: A QuickTime-based infrastructure for vision research displays**

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Modern computer-controlled raster displays allow precise control of arbitrary distributions of light over space, time, and colour, and have consequently become the standard display for vision research. A number of software systems have been developed that control raster displays in a manner suited to vision research. However, such systems are often limited to a narrow range of possible stimuli, or require excessive programming effort. All suffer from platform dependence, and are at risk of obsolescence as computer hardware and operating systems mature. The vision community is too small to create an up-to-date, platform-independent, high-level, general software infrastructure for visual displays. But by exploiting an existing commercial software infrastructure we may come close to that goal. QuickTime is a multimedia software architecture developed by Apple Computer and available on several computer platforms, including Apple Macintosh, Windows, and Silicon Graphics. It consists primarily of a file format and an application-programming interface, and is designed to simplify the manipulation and presentation of time-based media, notably video, animated graphics, and sound. Here I describe the advantages of QuickTime for vision research, and also describe a particular psychophysical display system, called ShowTime, based on this infrastructure. ShowTime software is available for free download at http://vision.arc.nasa.gov/showtime/.

◆ **Formal models of blur detection**

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The detection of blur is examined from the perspective of engineering research into passive, image-based autofocus methods in computer vision, automated microscopy, and consumer electronics, in order to understand what must be necessary for passive, image-based blur detection. The physiological optics literature on blur detection is then reviewed in light of the foregoing discussion, and I argue that the edge-detection and contrast-detection hypotheses are equivalent to spatial-frequency and image-variance algorithms, respectively, of computer vision. Finally, I describe a new instrument, the virtual lens, with which one can experimentally differentiate these two hypotheses.

◆ **Visual recognition of embedded pictures in left-handed and right-handed children**

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One of the main phenomena in visual perception is the separation of figure and ground (SFG). It is interesting to know how the mechanism of SFG develops and how it interacts with other visual operations, especially for left-handed children. To answer this question, we presented several embedded line pictures to 35 right-handed and 35 left-handed children aged 7–9 years. Stimuli were line drawings of two familiar objects. The stimuli were presented at 400–1000 ms in the centre of computer screen. After stimulus presentation a mask appeared, which consisted of several superimposed embedded pictures. The observer's task was to recognise and to name (orally) both of the stimulus pictures. The results show that left-handed children (especially the youngest group) have better performance in recognition of embedded pictures than right-handed children. Our interpretation assumes that, with respect to a certain subsystem of the SFG, left-handed children can more effectively implement the computational resources. This is, in our thinking, because control of primary hand is carried out by another hemisphere.

◆ **Visual fatigue and TV viewing**

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TV observers are exposed to three kinds of possible hazards: physical, moral, and psychological. TV viewing involves several effects, including flicker, inadequate contrast, and informational overload, that might produce undesirable consequences. Research into and development of better TV production and broadcasting techniques are required. We studied objective and subjective

indices of visual fatigue during TV viewing. Accommodation, eye blinking, and visual fatigue were measured as a function of flicker frequency and illumination conditions associated with the TV monitor. For most observers visual fatigue decreased during prolonged TV viewing.

◆ **Distinct features in alphabetical signs**

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In a previous study, we generated a set of random patterns which can be used as pseudo-alphabetical characters. In the present research, recognition was studied when these pseudo-alphabetical characters were degraded by adding visual noise. The amount of degradation was measured in terms of the Hamming distance (see Bienenstock and Malsburg, 1987 *Neurophysiology Letters* 1243). A direct relationship between the increase in Hamming distance and the loss of recognition was observed. For some characters, however, recognition was easier for small Hamming distances. These cases corresponded to pseudo-alphabetical characters endowed with incomplete distinctive features. These results are useful for determining to what extent the different features of alphabetical characters are perceptually resistant to noise.

◆ **Orientation and amodal completion**

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The perceived shape of an amodally completed figure depends on orientation. Previous findings (Srebotnjak, 1985, unpublished thesis, University of Trieste) indicate that the same region is perceived as a regular hexagon when its major axis is vertical and as a truncated square when its sides are vertical/horizontal. Different observers were shown the same configuration in these two orientations and asked to complete the partially occluded figure as a regular hexagon. Then, they were required to decide if a briefly flashed probe was within or outside the contour of the completed hexagon. The results indicate that the perceived position of the probe was affected by orientation in the expected direction. When the sides of the partially completed figure were vertical/horizontal, it was more likely for the probe to be perceived within the hexagon. This is consistent with the idea that completion according to good continuation is facilitated along vertical/horizontal directions, against bilateral symmetry. Bilateral symmetry dominates only when the axis is vertical.

◆ **Investigating the processing of occluded spatiotemporal patterns: The 'dynamic Poggendorff' effect**

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In order to investigate the processing and representation of spatiotemporal patterns under conditions of occlusion we devised a spatiotemporal completion task. Subjects saw a single black dot moving along an (invisible) straight oblique line. The middle segment of the motion path was occluded by a vertical bar so as to divide it into two visible segments. The stimulus can be thought of as a dynamic version of the 'Poggendorff' stimulus. Subjects had to adjust the position where the moving dot reappeared in order to bring both visible segments into alignment. We varied (i) the dot velocity: slow/middle/fast (5/10/15 deg s^{-1}), (ii) the occluding-bar width: thin/middle/thick (0.8/2.4/4.2 deg), (iii) the 'filling-mode' of the occluding bar: white/black–white/black. Twenty-seven conditions were obtained by permuting conditions in (i)–(iii). As dependent variable the alignment error (AE) was measured. A positive AE means that the adjusted segment was lower then the correct one.

We found that (a) the filling-mode has no influence on the AE; (b) an occluding bar leads to a positive AE, in analogy to the static Poggendorff effect; increasing the bar width leads to an increase of the AE by a factor of ~ 2.3; (c) increasing the dot velocity leads to a decrease of the AE by a factor of ~ 0.9. It is interesting that the presence of an occluding bar leads to a systematic (positive) AE. The dynamic Poggendorff effect thus clearly suggests a qualitative analogy between static and dynamic processing modes. Research reported by Eisenkolb et al (1998 *Perception* **27** Supplement, 188), on the other hand, suggests a drastic quantitative difference of the processing of static and dynamic stimuli. It is also probable that the task employed involves memory-based mechanisms important for prediction of courses of motion. This in turn does not by any means explain why there is a dynamic Poggendorff effect.

◆ **The perception of length changes in moving objects**

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Let us consider a horizontal rectangle (86 mm × 10 mm) travelling along the equator of a monitor screen at the velocity of 12.25 cm s^{-1} from left to right and vice-versa. During the motion, let the head move at a higher/lower speed, so that the length of the rectangle is increased/decreased. Thirty subjects were presented 44 stimulus situations where the rectangle varied in size (43 mm × 10 mm; 86 mm × 10 mm). They had to report whether the rectangle changed or not and, if it did, whether it lengthened or shrunk. The results showed that sensitivity for changes was better for the long rectangle, $F_{1,29} = 6.83$, $p < 0.001$; and that the threshold for change was lower for lengthening than for shortening in a rectangle travelling from right to left, $F_{1,29} = 13.40$, $p < 0.001$. Surprisingly, the differential threshold for the long rectangle (86 mm: lengthening = 5.41%, shrinkage = 7.56%) was smaller than that for the short rectangle (43 mm: lengthening = 6.69%, shrinkage = 9.77%). This apparent lack of confirmation of Weber's fraction may be explained by the differential sensitivity to the variations of some lengths compared to others, and deserves more experimentation.

AUTHOR INDEX

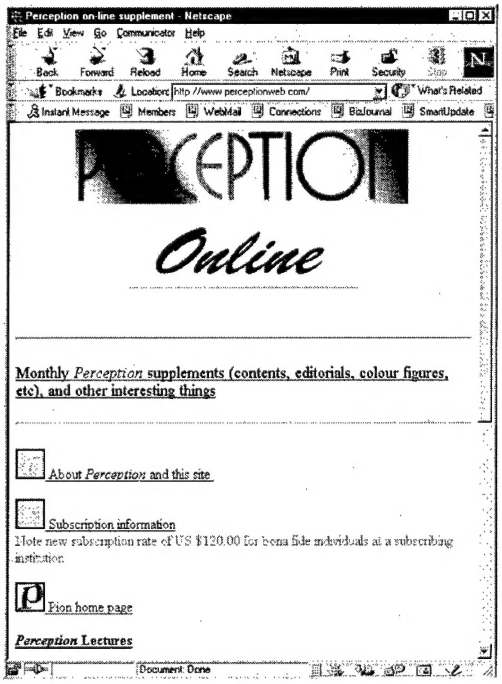
Note: de X, van X, van den X, von X are all indexed under X

LATE AMENDMENTS

The index entry for Angeli should have appeared as the following distinct pair of entries:

ECVP99 abstracts on the Internet

http://www.perceptionweb.com/ecvp99/



Details of the 22nd European Conference on Visual Perception (Trieste) are available on the *Perception* website at the above location. The site contains the Conference abstracts for all oral presentations, symposia, and poster sessions.

The abstracts are accessible by hypertext links from the online Conference programme or by word/substring search. There are about 500 abstracts in total. The abstracts are best viewed with a recent version of Netscape Navigator. Other browsers can be used, but mathematical terms might not be displayed correctly. Browsers should be set for Western font encoding (ISO-8859-1); other settings (such as Japanese) will display certain characters incorrectly.

The main *Perception* site (http://www.perceptionweb.com) is updated monthly with the latest contents and editorials for each issue together with any relevant supplementary material, such as colour images and animations. And, as a new feature, abstracts now appear for each article. Annual indexes and abstracts of various conferences are also available, together with details of forthcoming meetings. An e-mail alerting service lets you know when new material has been placed on the site. To take advantage of this free service, send a blank e-mail message to the address wwwper-request@pion.demon.co.uk, with subject line *subscribe*.

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